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Technical Note

February 1986

By C. A. Kodres

Sponsored by Naval Facilities
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Computer Program to Simulate the Thermal Characteristics of Heat Recovery Incinerators

ABSTRACT The computer model, HRI, is described. This model simulates the thermal characteristics of energy ("heat") recovery incinerators. The program takes descriptions of the fuel and of the incinerator as inputs then predicts system temperatures, steam generation rate, and energy recovery efficiency. There are options to include primary or secondary waterwalls, a water/firetube boiler, or combinations of these heat exchangers. Both starved and excess air operations are considered.

NAVAL CIVIL ENGINEERING LABORATORY, PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

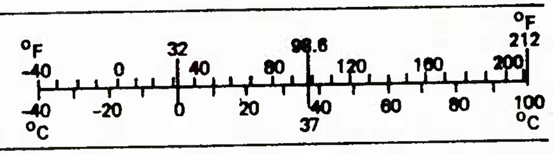
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

INTRODUCTION

This report describes HRI, a computer model that simulates the thermal characteristics of energy ("heat") recovery incinerators. The program predicts system temperatures, steam generation rate (energy is recovered as the internal energy of steam), and energy recovery efficiency from descriptions of the fuel and the incinerator.

The computer program was initially developed to help prepare a test program to parametrically examine the incinerators at the Naval Air Station (NAS), Jacksonville, Fla. (Ref 1). These incinerators are dual combustion chamber devices with a single-pass water tube heat exchanger located downstream from the second combustion chamber. Two major improvements were made to this first version of the model: (1) a capability to simulate primary or secondary combustion chamber waterwalls was added, and (2) the programmed combustion mechanism was changed from a sequential mode (Ref 1) to a diffusion mode (Ref 2). Figure 1 schematically illustrates the different incinerator configurations currently within the scope of the model.

The program is written in FORTRAN IV and has about 1,400 source statements. It was developed on a CDC 760/875; execution times of less than 1 second are typical. A PC version is discussed in the Appendix.

MATHEMATICAL MODELING

The simulation of the energy recovery incinerators is based on the hypothesized combustion reaction*:

$$C_{n_1}H_{n_2}O_{n_3}N_{n_4} + n_5H_2O + n_6O_2 + 3.76\ n_6N_2 \rightarrow$$

$$n_7CO_2 + (n_5 + n_8)\ H_2O + n_9CO + n_{10}O_2$$

$$+ (0.5\ n_4 + 3.76\ n_6)\ N_2 + n_{11}H_2 + n_{12}C \qquad (1)$$

In addition, it is assumed that:

1. Steady state exists.

2. The incinerator is operating at atmospheric pressure.

3. All gases are ideal.

*No attempt is made to distinguish between subscripts and coefficients. Numerical values are of interest here (i.e., number of moles), and both contribute in the same manner.

4. Kinetic and potential energy changes are negligible.

5. There is no dissociation; the reaction goes to completion regardless of the temperature.

6. Combustion is diffusion controlled, limited only by the mass flow rates of fuel and oxygen.

7. The products of combustion are perfectly mixed.

8. Therefore, all temperature gradients are normal to the incinerator walls; the individual components of the incinerator may be represented one-dimensionally.

The molar coefficients n_1 through n_5 are obtained from ultimate and proximate analyses of the fuel (waste); n_6 is from the air supplied for combustion. For starved air operation, Equation 1, is balanced by applying conservation of species and allocating available oxygen linearly to the hydrogen and carbon in such a manner that the combustion of both elements is complete exactly when stoichiometric conditions are reached,

$$n_2H + X_1\left(n_6 + \frac{n_3}{2}\right) O_2^{*} \rightarrow 2\,X_1\left(n_6 + \frac{n_3}{2}\right) H_2O$$

$$+ \left[\frac{n_2}{2} - 2\,X_1\left(n_6 + \frac{n_3}{2}\right)\right] H_2$$

$$n_1C + X_2\left(n_6 + \frac{n_3}{2}\right) O_2 \rightarrow 2\,X_2\left(n_6 + \frac{n_3}{2}\right) CO$$

$$+ \left[n_1 - 2\,X_2\left(n_6 + \frac{n_3}{2}\right)\right] C \quad , \quad 2\,X_2\left(n_6 + \frac{n_3}{2}\right) < n_1$$

$$n_1C + X_2\left(n_6 + \frac{n_3}{2}\right) O_2 \rightarrow 2\left[n_1 - X_2\left(n_6 + \frac{n_3}{2}\right)\right] CO$$

$$+ \left[2\,X_2\left(n_6 + \frac{n_3}{2}\right) - n_1\right] CO_2 \quad , \quad 2\,X_2\left(n_6 + \frac{n_3}{2}\right) \geqq n_1$$

where:

$$X_1 = \frac{n_2/4}{n_1 + n_2/4}$$

$$X_2 = \frac{n_1}{n_1 + n_2/4}$$

---

*The program actually allocates the elemental oxygen rather than O_2.

Stoichiometric air $\propto n_1 + n_2/4$. Unallocated oxygen, hydrogen, and carbon are assumed to be released as O_2, H_2, and C.

Carbon reacts with the oxygen to form carbon monoxide (Ref 3); any oxygen remaining oxidizes the carbon monoxide to form carbon dioxide. For excess air operation, water vapor and carbon dioxide are considered to be the only products of combustion.

Stoichiometric Air

Stoichiometric air is the air required to oxidize the fuel to water vapor and carbon dioxide,

$$C_{n_1}H_{n_2}O_{n_3}N_{n_4} + n_6O_2 + 3.76n_6N_2 \rightarrow n_7CO_2 + n_8H_2O + (0.5n_4 + 3.76n_6)N_2$$

$$n_{7,STOICH} = n_1 \ , \quad n_{8,STOICH} = \frac{n_2}{2}$$

$$n_{6,STOICH} = \frac{2n_{7,STOICH} + n_{8,STOICH} - n_3}{2}$$

$$\dot{M}_{AIR,STOICH} = [32 + 3.76\ (28)]\ n_{6,STOICH}\ \dot{M}_{FUEL,\ DRY}$$

where $\dot{M}_{FUEL,DRY}$ is the feed rate of waste (dry).

Heat of Pyrolysis

The heat absorbed in breaking down the fuel is primarily a heat of pyrolysis since most types of waste (e.g., paper and wood) are pyrolyzing solids. Regardless of the mode, the energy required to break down the fuel is easily calculated once the stoichiometric products of combustion have been determined,

$$Q_{FUEL} = HHV_{FUEL,DRY} - n_{7,STOICH}\ Q_{CO_2} - n_{8,STOICH}\ Q_{H_2O}$$

where: HHV = higher heating value of fuel (dry)

Q_{CO_2} = heat of formation of carbon dioxide

Q_{H_2O} = heat of formation of water (liquid)

Adiabatic Flame Temperature

If all the energy released during the combustion reaction is assumed to be available to heat the products, an upper limit to the flame temperature can be determined. This temperature is usually referred to as the adiabatic flame temperature.

First, subtract the ash to derive the composition of the fuel actually burned,

$$n_1 =^* n_1 - \left(\frac{\dot{M}_{ASH}}{\dot{M}_{FUEL,DRY}} \right) \text{ x (moles of carbon in ash), etc.}$$

Air supplied to the flame is one of the independent variables affecting incinerator performance. The coefficient n_6 of Equation 1 is determined directly from the underfire airflow to the flame. Once the fuel composition and the air (oxygen) have been established, Equation 1 is balanced using the method described above.

Subtracting the energy lost vaporizing the moisture in the fuel,

$$\hat{Q}_{LOST} = \text{(mass fraction of moisture in fuel) x (heat of vaporization of water at a pressure of 1 atmosphere)}$$

the net heat released to the flame can be calculated,

$$\dot{q}_{FLAME} = \left(n_7 \, Q_{CO_2} + n_8 \, Q_{H_2O} + n_9 \, Q_{CO} - Q_{FUEL}^{**} - \hat{Q}_{LOST} \right) \dot{M}_{FUEL,\ DRY}$$

Since the mass flow through the flame is known,

$$\dot{M}_{FLAME} = \dot{M}_{FUEL,\ WET} + \dot{M}_{AIR} - \dot{M}_{ASH}$$

the adiabatic flame temperature can be determined by applying conservation of energy,

$$T_{FLAME} = T_{DATUM} + \left[\dot{q}_{FLAME} + \dot{M}_{FUEL,DRY} \, \Delta h_{FUEL} \, (T_\infty) + \dot{M}_{AIR} \, C_{P,AIR} \, (T_\infty) \, \Delta T_\infty \right] \Big/ \left[\dot{M}_{FLAME} \, C_{P,MIX} \, (T_{FLAME}) + C_{P,ASH} \, \dot{M}_{ASH} \right] \qquad (2)$$

---

*Perhaps different symbols should be used; the value of n, on the LHS is replacing the input value.

**For most fuels, $Q_{FUEL} < 0$.

where: T_{DATUM} = reference temperature of defined properties

T_∞ = ambient temperature

$C_P(T)$ = specific heat at temperature T

$\Delta T_\infty = T_\infty - T_{DATUM}$

$\Delta h(T)$ = enthalphy at temperature T relative to T_{DATUM}

$C_{P,MIX} = \sum_{MIXTURE}$ (mole fraction x $C_{P,MEAN}$)

$$C_{P,MEAN}(T_2) \equiv \frac{1}{T_2 - T_{DATUM}} \int_{T_{DATUM}}^{T_2} C_P(T)\, dT$$

Note that the temperature dependency of specific heat* makes Equation 2 nonlinear. The relationships of Sweigert and Beardsley (Ref 4) were used to calculate specific heats as a function of temperature. These relationships and Equation 2 were solved simultaneously.

Primary Combustion Chamber Temperatures

Temperatures in the primary combustion chamber (PCC) are calculated by solving the energy equations governing the flame front, the combustion chamber interior, and the walls of the PCC. Combustion products in both the flame and the PCC interior are assumed to be perfectly mixed. The homogeneous flame temperature derived in this manner can be considered a lower limit to the actual flame temperature.

The flame composition is already known from the adiabatic calculations; the flame chemistry is assumed independent of temperature. Composition of the combustion products in the primary combustion chamber is determined in an analogous manner, taking into account oil injected into the chamber, overfire air, and possible air leakage.

If underfire air is insufficient for the complete combustion of the fuel (wastes) and the oil, PCC overfire air and leakage will induce further chemical reaction and, thus, energy released in the primary combustion chamber,

$$\dot{q}_{PCC} = \Big(n_7\, Q_{CO_2} + n_8\, Q_{H_2O} + n_9\, Q_{CO} - Q_{FUEL} - Q_{OIL} - \hat{Q}_{LOST} \Big)\, \dot{M}_{FUEL,DRY} - \dot{q}_{FLAME}$$

Energy terms included in the PCC analyses are illustrated schematically in Figure 2.

*The specific heat of ash is assumed to be a constant.

Applying conservation of energy to the flame,*

$$\dot{M}_{FLAME}\, C_{P,MIX}(T_{FLAME})\, \Delta T_{FLAME} + \dot{M}_{ASH}\, C_{P,ASH}\, \Delta T_{FLAME} + \dot{q}_{RAD,F\rightarrow W}$$

$$+ \dot{q}_{RAD,F\rightarrow G} - \dot{q}_{FLAME} - \dot{M}_{FUEL,DRY}\, \Delta h_{FUEL}(T_{\infty})$$

$$- \dot{M}_{AIR}\, C_{P,AIR}(T_{\infty})\, \Delta T_{\infty} = 0 \qquad (3)$$

where: $\dot{q}_{RAD,F\rightarrow W}$ = radiation from flame to walls of PCC

$$= A_{FLAME}\, \sigma \left\{ \left[1 - \varepsilon_{MIX}(T_{FLAME})\right] T^4_{FLAME} - \left[1 - \varepsilon_{MIX}(T_{WALLS})\right] T^4_{WALLS} \right\}$$

$\dot{q}_{RAD,F\rightarrow G}$ = radiation from flame to products of combustion inside the PCC

$$= A_{FLAME}\, \sigma \left[\varepsilon_{MIX}(T_{FLAME})\, T^4_{FLAME} - \varepsilon_{MIX}(T_{PCC})\, T^4_{PCC}\right]$$

T_{FLAME} = homogeneous flame temperature

T_{PCC} = homogeneous temperature of products of combustion in PCC

T_{WALLS} = PCC inside wall temperature

A_{FLAME} = surface area of flame front

σ = Stefan-Boltzmann constant

Both the flame and inside of the PCC walls are assumed to act as black bodies. The products of combustion are assumed gray; the emissivities of these gases at temperature T, $\varepsilon_{MIX}(T)$, are derived by curve fitting the data of Hottel et al. (Ref 5). Gas emissivities are thus a function of both composition and temperature. The configuration factor from the flame to the PCC walls is assumed to be 1.

Applying conservation of energy to the interior of the primary combustion chamber,

---

*The flame is considered to be the region influenced by underfire air. It does not touch the PCC walls (i.e., there is no convection heat transfer between the flame and the walls).

$$\dot{M}_{PCC}\, C_{P,MIX}(T_{PCC})\, \Delta T_{PCC} + \dot{q}_{RAD,G\to W} + \dot{q}_{CONV,G\to W}$$

$$- \dot{q}_{PCC} - \dot{q}_{RAD,F\to G} - \dot{M}_{FLAME}\, C_{P,MIX}(T_{FLAME})\, \Delta T_{FLAME}$$

$$- \dot{M}_{OIL}\, \Delta h_{OIL}(T_\infty) - \dot{M}^{*}_{AIR,LEAK}\, C_{P,AIR}(T_\infty)\, \Delta T_\infty = 0 \tag{4}$$

where: $\dot{q}_{RAD,G\to W}$ = radiation from combustion gases to PCC walls

$$= A_{PCC}\, \sigma \left[\varepsilon_{MIX}(T_{PCC})\, T^4_{PCC} - \varepsilon_{MIX}(T_{WALLS})\, T^4_{WALLS} \right]$$

$\dot{q}_{CONV,G\to W}$ = convection heat transfer to PCC wall interior

$$= h_{CONV,PCC}\, A_{PCC}(T_{PCC} - T_{WALLS})$$

A_{PCC} = surface area of PCC walls

$h_{CONV,PCC}$ = convection film coefficient

Finally, applying conservation of energy to the walls,

$$\dot{q}_{COND} - \dot{q}_{RAD,F\to W} - \dot{q}_{RAD,G\to W} - \dot{q}_{CONV,G\to W} = 0 \tag{5}$$

$$\dot{q}_{RAD,W\to\infty} + \dot{q}_{CONV,W\to\infty} - \dot{q}_{COND} = 0 \tag{6}$$

where: $\dot{q}_{COND}$ = conduction heat transfer through the walls

$$= KA_{PCC}(T_{WALLS} - T_{SHELL})$$

$\dot{q}_{CONV,W\to\infty}$ = radiation off outer surface of PCC walls

$$= h_{CONV,\infty}\, A_{PCC}(T_{SHELL} - T_\infty)$$

$\dot{q}_{RAD,W\to\infty}$ = radiation off outer surface of PCC walls

$$= A_{PCC}\, \sigma\, \varepsilon_{SHELL}(T^4_{SHELL} - T^4_\infty)$$

T_{SHELL} = temperature of outer skin of PCC

ε_{SHELL} = emissivity of outer skin of PCC

K = conductance of PCC walls

Equations 3 through 6, along with the relationships derived for temperature variations of specific heat and emissivity, are solved simultaneously for the temperatures T_{FLAME}, T_{PCC}, T_{WALLS}, and T_{SHELL}.

*Overfire air and PCC leakage are combined.

Secondary Combustion Chamber Temperatures

Temperatures of the combustion products and walls in the secondary combustion chamber (SCC) are calculated in a manner analogous to the PCC problem. The energy equations governing the interior of the SCC, the inner walls, and outer skin are solved simultaneously while allowing both specific heat and emissivity to vary with temperature. If combustion is not completed in the PCC, secondary air will induce further chemical reactions and will require an additional heat source term in the energy equation governing the SCC interior.

Heat Recovery Boiler

The boiler unknowns are the steam generated, the total heat transferred between the combustion products and the feed water/steam, and the temperature of the combustion gases as they enter the stack. Temperature and pressure of the feed water and steam are assumed to be known.

Waterwalls are simulated by setting the inner wall temperature of the combustion chamber equal to the steam temperature (i.e., ignoring the very small temperature gradients through the metal of the waterwalls and through the boundary layer on the feed water/steam side of the system). Heat transfer to these walls is already a part of the analysis of the PCC; steam generation merely involves bookkeeping the heat fluxes to the waterwalls.

Modeling a convection boiler is more complex. It is accomplished by applying conservation of energy to the combustion gases, the feed water/steam, and the overall heat recovery boiler (individual energy terms are illustrated in Figure 3),

$$(\dot{M}_{SCC} + \dot{M}_{AIR,LEAK})\, C_{P,MIX}(T_{STACK})\, \Delta T_{STACK} + \dot{q}_{STEAM} - \dot{M}_{SCC}\, C_{P,MIX}(T_{SCC})\, \Delta T_{SCC} - \dot{M}_{AIR,LEAK}\, C_{P,AIR}(T_\infty)\, \Delta T_\infty = 0 \tag{7}$$

$$\dot{M}_{STEAM}\, \Delta h_{STEAM}(T_{STEAM}) + BD\, \dot{M}_{STEAM}\, \Delta h_{STEAM}\, (T_{STEAM}) - \dot{q}_{STEAM} - (1 + BD)\, \dot{M}_{STEAM}\, \Delta h_{FEED}(T_{FEED}) = 0 \tag{8}$$

$$\dot{q}_{STEAM} - U_{MEAN}(\dot{M},T)\, A_{BOILER}\, LMTD = 0 \tag{9}$$

where:

$\dot{M}_{SCC}$ = mass flow out of the secondary combustion chamber

$\dot{M}_{AIR,LEAK}$ = air leakage down the dump stack

$\dot{M}_{STEAM}$ = steam generated in the boiler

BD = boiler blowdown as a fraction of steam generated

$\Delta h_{FEED}(T_{FEED})$ = enthalpy of feed water at temperature T_{FEED} relative to T_{DATUM}

$\Delta h_{STEAM}(T_{STEAM})$ = enthalpy of steam at T_{STEAM} relative to T_{DATUM}

$\dot{q}_{STEAM}$ = heat transferred between combustion products and feed water/steam

T_{SCC} = homogeneous temperature of products of combustion in SCC

T_{STEAM} = temperature of the steam exiting the boiler

T_{STACK} = stack gas temperature (i.e., temperature of combustion gases as they exit the boiler)

A_{BOILER} = total surface area of boiler tubes

LMTD = logarithmic mean overall temperature difference (Figure 4)

$$\equiv \frac{(T_{SCC} - T_{STEAM}) - (T_{STACK} - T_{FEED})}{\ln \dfrac{T_{SCC} - T_{STEAM}}{T_{STACK} - T_{FEED}}}$$

The boiler overall heat transfer coefficient, $U_{MEAN}(\dot{M},T)$, varies with both temperature and flow rate. The magnitude of this coefficient is determined by noting that the resistance to heat transfer from the combustion gases is the dominant resistance and, thus, only gas properties have an appreciable effect on U_{MEAN}. A staggered tube configuration (Ref 5) is assumed,

$$N_{Nu} \propto N_{Re}^{0.6} \, N_{Pr}^{0.33}$$

where: N_{Nu} = Nusselt number

N_{Re} = Reynolds number

N_{Pr} = Prandtl number

Observing that the variation in the one-third power of the Prandtl number is negligible, and lumping the geometry into the constant of proportionality, $\bar{U}$,*

*U is backed-calculated from boiler performance data that are part of the input.

$$U_{MEAN} = \bar{U}\, k_{AVG}(T_{AVG}) \left[\frac{\dot{M}_{SCC} + \dot{M}_{AIR\ LEAK}}{\mu_{AVG}(T_{AVG})} \right]^{0.6} \tag{10}$$

where: $T_{AVG} = (1/4)\ (T_{SCC} + T_{STACK} + T_{FEED} + T_{STEAM})$

$k_{AVG}(T_{AVG})$ = thermal conductivity of combustion products at the average temperature T_{AVG}

$\mu_{AVG}(T_{AVG})$ = viscosity of combustion products at temperature T_{AVG}

$$k_{AVG}, \mu_{AVG} \propto \frac{T_{AVG}^{\ 1.5}}{225 + T_{AVG}} \tag{11}$$

Equations 11 are usually referred to as the Eucken equations and were derived using the methods of the kinetic theory (Ref 6). For this simulation, the constants of proportionality are determined by assuming that the products of combustion behave in the same manner as air.

Equations 7 through 11 are solved simultaneously.

EFFICIENCY CRITERIA

The performance of the heat recovery incinerator was evaluated by applying the heat loss method suggested for steam generating units by the American Society of Mechanical Engineers (Ref 7). "The efficiency is equal to 100% minus a quotient expressed in percent. The quotient is made up of the sum of all accountable losses as the numerator, and heat in the fuel plus heat credits as the denominator." Or, in mathematical form,

$$\eta \equiv 1 - \frac{\Sigma \text{ LOSSES}}{\Sigma \text{ INPUT}}$$

Not all losses are included in the summations, and some are slightly different from those suggested by Reference 7 to be compatible with the mathematical simulation.

Losses

Heat lost vaporizing moisture with waste $= \dot{M}_{MOIST}\ \Delta h_{fg}$

Vaporization of water generated by burning hydrogen in waste

$$= 18\ n_2\ \Delta h_{fg}\ \dot{M}_{FUEL}$$

Carbon carried out with ash $= \dot{M}_{ASH}\ C_{ASH}\ Q_{CO_2}$

Sensible heat in ash $= C_{P,ASH} \dot{M}_{ASH} \Delta T_{FLAME}$

Heat transfer through walls of PCC $= KA_{PCC}(T_{PCC,WALLS} - T_{PCC,SHELL})$

Heat transfer through walls of SCC $= KA_{SCC}(T_{SCC,WALLS} - T_{SCC,SHELL})$

Incomplete combustion

$$= \dot{M}_{FUEL} \left[n_9 \left(Q_{CO_2} - Q_{CO} \right) + n_{11} Q_{H_2O} + n_{12} Q_{CO_2} \right]$$

Sensible heat in stack gases

$$= (\dot{M}_{SCC} + \dot{M}_{AIR,LEAK}) C_{P,MIX}(T_{STACK}) \Delta T_{STACK}$$

Loss of steam due to blowdown $= \dot{M}_{STEAM}[BD/(1 - BD)] \Delta h_{STEAM}(T_{STEAM})$

Inputs

Chemical plus sensible energy in waste

$$= \dot{M}_{FUEL} HHV_{FUEL,DRY} - \dot{M}_{AIR} C_{P,AIR}(T_\infty) \Delta T_\infty$$

$$+ \left(\dot{M}_{SCC} + \dot{M}_{AIR,LEAK} \right) C_{P,AIR}(T_\infty) \Delta T_\infty$$

Enthalpy of combustion air $= \dot{M}_{AIR} C_{P,AIR}(T_\infty) \Delta T_\infty$

Chemical plus sensible energy in oil $\cong \dot{M}_{OIL} HHV_{OIL}$

Enthalpy of boiler feed water $= \dot{M}_{STEAM}(1 + BD) \Delta h_{FEED}(T_{FEED})$

Sensible heat of products of combustion entering boiler

$$= (\dot{M}_{SCC} + \dot{M}_{AIR,LEAK}) C_{P,MIX} (T_{SCC}) \Delta T_{SCC}$$

The power required to run accessories is input directly.

NUMERICAL METHODS

The numerics involved in the simulation are straightforward. The only portions of the program that might be difficult to follow are those sections involving the simultaneous solution of the component energy equations (e.g., Equations 3 through 6). Variable properties make these equations nonlinear; an iterative technique is necessary. The Newton-Raphson iteration (Ref 8) was selected for this application.

With this technique, an initial estimate is made of the value of the unknowns, e.g.,

$$T_1 = T_{FLAME} \sim 3{,}500°R$$

$$T_2 = T_{PCC} \sim 3{,}200°R$$

$$T_3 = T_{WALLS} \sim 3{,}000°R$$

$$T_4 = T_{SHELL} \sim 1{,}000°R$$

A Jacobian of the energy equations is formed,

$$F_1 = F_1(T_1, T_2, T_3, T_4) = 0$$

$$F_2 = F_2(T_1, T_2, T_3, T_4) = 0$$

$$F_3 = F_3(T_1, T_2, T_3, T_4) = 0$$

$$F_4 = F_4(T_1, T_2, T_3, T_4) = 0$$

$$[J] = \begin{bmatrix} \frac{\partial F_1}{\partial T_1} & \frac{\partial F_1}{\partial T_2} & \frac{\partial F_1}{\partial T_3} & \frac{\partial F_1}{\partial T_4} \\ \frac{\partial F_2}{\partial T_1} & \frac{\partial F_2}{\partial T_2} & \frac{\partial F_2}{\partial T_3} & \frac{\partial F_2}{\partial T_4} \\ \frac{\partial F_3}{\partial T_1} & \frac{\partial F_3}{\partial T_2} & \frac{\partial F_3}{\partial T_3} & \frac{\partial F_3}{\partial T_4} \\ \frac{\partial F_4}{\partial T_1} & \frac{\partial F_4}{\partial T_2} & \frac{\partial F_4}{\partial T_3} & \frac{\partial F_4}{\partial T_4} \end{bmatrix}$$

inverted,

$$[J] = [J]^{-1}$$

and used to improve the initial estimate,

$$T_i = T_i - \sum_{j=1}^{n} J_{i,j} \cdot F_j$$

For example,

$$T_{FLAME} = 3500 - \sum_{j=1}^{4} J_{1,j} \cdot F_j$$

This improved estimate now replaces the initial estimate; the variable properties, specific heat and emissivity, are updated based upon the new temperatures, and the calculations are repeated, producing a still better estimate of the unknowns. The iteration continues until some preset limit to the number of iterations is reached (called ITER in the computer program) or until the change in the calculated value of all the unknowns is less than some preset tolerance (called TOL in the program).

VALIDATION OF MODEL

The most credible method of determining the accuracy of a computer program is to compare predicted values with corresponding experimental data. When incinerators are being modeled, however, such a comparison is difficult because of the extensive data required and because many necessary measurements are not easily obtained (e.g., fuel composition, feed rate, and combustion and leakage airflows). No incinerator data, sufficient to validate all the HRI options, have been published.

The evaluation tests of the energy recovery incinerator at the Naval Station (NS), Mayport, Fla. (Ref 9), are probably the most comprehensive. This incinerator is an excess air device with a single-pass water tube boiler located downstream from the secondary combustion chamber as shown schematically by Figure 5. Key data are also included: arithmetic averages of the 24 hourly readings taken on 9 Dec 1980.

Ultimate and proximate analyses of the waste were conducted once. The only gas flow measured was the total mass flow out the stack, but this variable was monitored continuously. SCC combustion air was set at 20% in excess of the air required to stoichiometrically burn SCC oil. Oil consumption was monitored, and airflow to the PCC, including infiltration, was determined by subtraction. A ratio was computed from the underfire/overfire split on the basis of blower capacities. All other inputs and steam generation were measured directly and continuously.

Table 1 is a comparison of the predicted* and measured performance of the Mayport incinerator. This table provides an indication of the capability of the program to simulate excess air operation and to predict steam generation when a convection boiler is used. In addition, the mass and energy transfer calculations leading to the prediction of an energy recovery efficiency are common to all configurations.

Tests conducted at the National Bureau of Standards (Ref 2 and 10) suggest that the starved air combustion of solid wastes in an incinerator is diffusion controlled. In a diffusion flame, part of the waste (actually the products of the pyrolysis of the waste) would burn completely to

---

*The HRI simulation of the Mayport evaluation tests is included as one of the examples presented later in this report.

water and carbon dioxide, as much as the air supply would allow, and the rest would remain unchanged. This mechanism is mathematically very simple; the energy released and the quantities of the combustion products are linearly proportional to the air supplied.

The other extreme is the equilibrium flame (i.e., combustion is controlled by chemical reaction rates). The energy release and the composition of the combustion products are a complex function of temperatures, available oxygen, and the chemical composition of the waste.

A modified diffusion flame mechanism is built into the model. Rather than being oxidized directly to carbon dioxide, carbon is assumed to burn in stages, with carbon monoxide formed initially. If additional air is available, the carbon monoxide is oxidized to form carbon dioxide. Carbon normally burns in such a manner (Ref 3), and this modification was made to improve the predicted properties of the combustion products.

The energy released during starved air combustion is examined in Figures 6 and 7 with the combustion mechanism as a parameter. (Equilibrium compositions were determined using the program of Reference 11). When burning cellulose, the major ingredient in most types of solid waste, differences in the energy released are negligible. With plastic, differences are small. Thus, the program HRI can be expected to accurately predict the energy released during starved air incineration regardless of the validity of the assumed combustion mechanism.

Validation of the predicted waterwall performance is more difficult and cannot be made using theoretical arguments. A comparison with data is necessary. Heat transfer to the waterwalls is the critical parameter, and the data must be comprehensive enough to separate the convective and radiative components of the heat flux. Emissivity calculations become very important; the program must be adequately predicting gas compositions, a problem particularly severe for starved air operation. Examination of the accuracy of the waterwall simulation will be left to future users.

INPUT INSTRUCTIONS

All input variables are real and are input in field widths of 10 except incinerator TYPE, which is an integer and is input in a field width of 5. The input format is illustrated by Table 2; input variables are defined in Table 3.

Engineering units are used throughout: pounds mass (lb), feet (ft), degrees Fahrenheit (°F), and British thermal units (Btu).

COMMENTS ON USE OF PROGRAM

This section elaborates upon aspects of the computer program that might not be obvious to users.

Convergence of Solution to Energy Equations

The solution of the energy equations is an iteration, continuing until some preset limit to the number of iterations is reached (called ITER in the program) or until the change in the calculated value of all the unknowns is less than some preset tolerance (called TOL in the program). ITER and TOL are input as data, setting ITER = 100 and TOL = 1. Normally, the energy equations converge to within this tolerance after four or five iterations or they begin to diverge, and little is gained by increasing ITER. TOL can be changed but, again, little is gained; the expectation of accuracies greater than ±1°F is unrealistic, and the program execution time associated with this tolerance is not significant.

If the solution to the energy equations should diverge, the run is aborted and an error message is printed describing the problem, e.g.,

```
***********************************************************
ITERATION FOR ADIABATIC FLAME TEMPERATURE IS DIVERGING
***********************************************************
```

This rarely occurs, and the cause is usually a poor initial guess for the value of the unknowns being determined. The problem can be cured by going into the program and changing these initial guesses (the pertinent variables are identified by comment statements).

Single Combustion Chamber Configurations

Incinerator configuration is input by assigning proper values to the variable TYPE and to the appropriate areas. Usually, this is sufficient. If there is only one combustion chamber, however, the second combustion chamber area cannot just be set equal to 0 (i.e., ASCC $\neq$ 0) because this introduces the identity 0 = 0 into the Newton-Raphson iteration and leads to uncertain results. To simulate a single combustion chamber incinerator, assign a very small value to ASCC.

Waterwall Areas

When waterwall configurations are examined, it is assumed that the surface area of the relevant combustion chamber is completely covered with tubes (i.e., the combustion chamber wall area is exactly equal to the waterwall heat transfer surface). APCC or ASCC is set (input) equal to this value.

Generally, waterwalls do not cover the entire combustion chamber wall. Thus, there is some error associated with this approach. For example, heat transfer losses out through nonwaterwall-covered surfaces are neglected, and the radiation shape factor* from the flame to the waterwalls is not identically equal to 1 as assumed in the model. Notwithstanding, when waterwalls are used, flame temperatures are low and heat transfer losses out through the walls amount to only 1% or so. Incinerators with shape factors much less than 1 are poorly designed.

Convective Heat Transfer Coefficients

Without knowing flow characteristics, convective film coefficients, both inside the combustion chambers and off the outer surfaces of the incinerator, can only be estimated. If there are no waterwalls, this

*Sometimes called the configuration factor, it is the fraction of the energy leaving the flame that arrives at the waterwalls.

shortcoming is minor; the dominant resistance to heat transfer out the walls is the resistance to conduction through the walls. The magnitude of this resistance is known: wall thickness divided by thermal conductivity. (It is actually the inverse of this resistance, thermal conductance, that is input.) When waterwall configurations are studied, convection heat transfer is important; steam generation is a strong function of convection heat transfer from the combustion products to the waterwalls. Some attempt to predict waterwall film coefficients is recommended. When this is not possible or when HRI is only being used for a preliminary study, the range of film coefficient offered is shown in Table 4. The coefficient of convective heat transfer off the outer surfaces of the incinerator, HCONV(3), has little effect on the operation of any configuration.

Emissivities

Emissivities of the combustion products are calculated by the program via subroutine EMISS. The emissivity of the outer shell of the incinerator is input as ESHELL but has little effect on the operation of the incinerator. Values of ESHELL ~ 0.75 are reasonable.

Mean Beam Lengths

Mean beam length is a calculation convenience used when determining radiation to or from absorbing-emitting gases. It may be thought of as "the radius of a gas hemisphere such that it radiates a flux to the center of its base equal to the average flux radiated to the area of interest by the actual volume of gas" (Ref 12). Mean beam lengths are program inputs. Values depend upon the shape of the combustion chamber being examined. Most radiation texts (Ref 5 and 12) include tables summarizing relationships for calculating mean beam length (e.g., for a cube radiating to one of its faces),

$$\text{Mean beam length} \approx 0.6 \times \text{length of a side}$$

Convection Boiler Design Point

The overall heat transfer coefficient of a convection type of energy recovery boiler is determined in the program by making a ratio from a design point using Reynolds numbers (see Equation 10). This design point is input. Normally, the required information can be acquired from the boiler nameplate. The following design point is typical for single-pass water tube boilers:

$U = 9.24$ Btu/hr-ft^2-°F

TIN = 1,800°F

TOUT = 500°F

FLOW = 17,000 lb/hr

ABOIL = 1,000 ft^2

DESCRIPTION OF OUTPUT

First, the input is duplicated. Following the pertinent calculations, energy released, gas flows, temperatures, and the compositions of the combustion gases in each section of the incinerator are output. Calculated properties (i.e., specific heats and emissivities) are output whenever their values are changed. Finally, the performance of the heat exchangers and the overall energy recovery incinerator is summarized.

EXAMPLES

To illustrate the potential of the model, four incinerators, each having a different configuration, are simulated. Except for the facility at NS Mayport, published descriptions of these incinerators are incomplete. When necessary, typical values are assumed (Ref 13 and 14).

Morse Boulger Plant No. 1 (Ref 15)

This incinerator, shown in Figure 8, is an excess air device with a single combustion chamber and no energy recovery boiler.

Input:

```
16670.    6200.
 37.29     4.99    32.11     0.46    25.15
 20.00    52.70     7.30    20.00
 2050.    1417.
    5.       0.       0.       0.      95.
    0.       0.   19700.
   86.      12.      0.5      0.      1.5
  500.
  954.       0.     880.       0.       0.
    0.       0.       0.
  933.    4067.      10.      50.      50.       5.     0.75     0.75
   70.     0.75      4.7      3.9
 1
```

Output:

FEED RATES AND BOUNDARY CONDITIONS

```
     FUEL (WASTE) MASS FEED RATE = 16670. LB/HR WET
     HIGHER HEATING VALUE OF FUEL =  6200. BTU/LB DRY

     ULTIMATE ANALYSIS OF FUEL                    PROXIMATE ANALYSIS OF FUEL
      (PERCENT OF DRY WEIGHT)                         (PERCENT OF WEIGHT)
     CARBON.......   37.29                        MOISTURE.........   20.00
     HYDROGEN.....    4.99                        VOLATILE MATTER..   52.70
     OXYGEN.......   32.11                        FIXED CARBON.....    7.30
     NITROGEN.....     .46                        ASH..............   20.00
     OTHER........   25.15

     ASH REMOVAL RATE = 2050. LB/HR
     HIGHER HEATING VALUE OF ASH = 1417. BTU/LB

     ULTIMATE ANALYSIS OF ASH
      (PERCENT OF DRY WEIGHT)
     CARBON.......    5.00
     HYDROGEN.....    0.00
     OXYGEN.......    0.00
     NITROGEN.....    0.00
     OTHER........   95.00

     OIL FLOW TO PRIMARY COMBUSTION CHAMBER =    0. LB/HR
     OIL FLOW TO SECONDARY COMBUSTION CHAMBER =    0. LB/HR
     HIGHER HEATING VALUE OF OIL = 19700. BTU/LB

     ULTIMATE ANALYSIS OF OIL
      (PERCENT OF DRY WEIGHT)
     CARBON.......   86.00
     HYDROGEN.....   12.00
     OXYGEN.......     .50
     NITROGEN.....    0.00
     OTHER........    1.50

     COMBUSTION AIR
       TO PRIMARY COMBUSTION CHAMBER (UNDERFIRE) =  954. LB/MIN
       TO PRIMARY COMBUSTION CHAMBER (OVERFIRE) =  880. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =    0. LB/MIN
       TO (WITH) PRIMARY OIL BURNER =    0. LB/MIN
       TO (WITH) SECONDARY OIL BURNER =    0. LB/MIN

     LEAKAGE AIR
       TO PRIMARY COMBUSTION CHAMBER =    0. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =    0. LB/MIN
       DOWN THE DUMP STACK =    0. LB/MIN

     AMBIENT AIR TEMPERATURE =  70. DEGF
```

HEAT TRANSFER PARAMETERS

SURFACE AREA OF FLAME FRONT = 933. SQFT
SURFACE AREA OF PCC = 4067. SQFT
SURFACE AREA OF SCC = 10. SQFT
EMISSIVITY OF OUTER SURFACE OF INCINERATOR = .75

CONVECTION FILM COEFFICIENTS
INNER SURFACE OF PCC = 50. BTU/HR-SQFT-DEGF
INNER SURFACE OF SCC = 50. BTU/HR-SQFT-DEGF
OUTER SURFACE OF INCINERATOR = 5. BTU/HR-SQFT-DEGF
THERMAL CONDUCTANCE THRU WALLS
OF PRIMARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
OF SECONDARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
MEAN BEAM LENGTH
OF PRIMARY COMBUSTION CHAMBER = 4.70 FT
OF SECONDARY COMBUSTION CHAMBER = 3.90 FT

INCINERATOR HAS NO BOILERS

AIR REQUIRED FOR STOICHIOMETRIC COMBUSTION OF SOLID WASTE = 1022.65 LB/MIN
HEAT ABSORBED IN BREAKING DOWN FUEL = -2123. BTU/LB

PRODUCTS OF COMBUSTION OF SOLID WASTE WITH STOICHIOMETRIC AIR
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3673
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN...........	0.0000
NITROGEN..........	3.5331
HYDROGEN..........	0.0000
CARBON...........	0.0000

FUEL (WASTE) MASS FEED RATE = ***** LB/HR DRY
HEAT RELEASED IN FLAME ZONE = .5193E+04 BTU/LB OF DRY FUEL
HEAT LOST VAPORIZING THE MOISTURE IN THE FUEL = .2426E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU THE FLAME = .7186E+05 LB/HR
THEORETICAL (ADIABATIC) FLAME TEMPERATURE = 2939. DEGF

PRODUCTS OF COMBUSTION OF SOLID WASTE IN FLAME ZONE
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.2250
WATER VAPOR.......	.6800
CARBON MONOXIDE...	.0726
OXYGEN...........	0.0000
NITROGEN..........	3.2732
HYDROGEN..........	.0021
CARBON...........	0.0000

HOMOGENEOUS FLAME TEMPERATURE = 2152. DEGF

HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER = .4261E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU PRIMARY COMBUSTION CHAMBER = .1247E+06 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN PRIMARY COMBUSTION CHAMBER = 1925. DEGF
PRIMARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1963. DEGF
PRIMARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 271. DEGF

SPECIFIC HEAT OF PCC COMBUSTION PRODUCTS = .29 BTU/LB-DEGF
EMISSIVITY OF PCC COMBUSTION PRODUCTS = .254

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE PRIMARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3391
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.8579
NITROGEN..........	6.2882
HYDROGEN..........	0.0000
CARBON............	0.0000

HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER = -.2910E-10 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU SECONDARY COMBUSTION CHAMBER = .1247E+06 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN SECONDARY COMBUSTION CHAMBER = 1925. DEGF
SECONDARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1906. DEGF
SECONDARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 265. DEGF

SPECIFIC HEAT OF SCC COMBUSTION PRODUCTS = .29 BTU/LB-DEGF
EMISSIVITY OF SCC COMBUSTION PRODUCTS = .233

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE SECONDARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3391
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.8579
NITROGEN..........	6.2882
HYDROGEN..........	0.0000
CARBON............	0.0000

THE STACK GAS PROPERTIES ARE APPROXIMATELY EQUAL TO THE SECONDARY COMBUSTION CHAMBER PROPERTIES

Naval Station, Mayport, Fla. (Ref 9)

The incinerator at NS Mayport is used to validate the program and is described, in detail, in an earlier section of this report. It is shown schematically in Figure 5.

Input:

2060.	6854.						
38.69	5.12	27.17	0.81	28.21			
25.10	46.96	5.17	22.77				
493.	1417.						
4.6	0.	0.	0.	95.4			
0.	314.	19700.					
86.	12.	0.5	0.	1.5			
586.							
243.	237.	0.	0.	88.			
0.	0.	0.					
135.	1183.	2094.	50.	50.	1.0	0.25	0.25
80.	0.75	5.3	5.3				
2							
4426.	180.	148.	370.	1196.	342.	172.	0.10
4.05	1500.	540.	4.63E4				

Output:

FEED RATES AND BOUNDARY CONDITIONS

```
     FUEL (WASTE) MASS FEED RATE =  2060. LB/HR WET
     HIGHER HEATING VALUE OF FUEL =  6854. BTU/LB DRY

     ULTIMATE ANALYSIS OF FUEL                    PROXIMATE ANALYSIS OF FUEL
      (PERCENT OF DRY WEIGHT)                         (PERCENT OF WEIGHT)
     CARBON.......   38.69                        MOISTURE.........   25.10
     HYDROGEN.....    5.12                        VOLATILE MATTER..   46.96
     OXYGEN.......   27.17                        FIXED CARBON.....    5.17
     NITROGEN.....     .81                        ASH..............   22.77
     OTHER........   28.21

     ASH REMOVAL RATE =  493. LB/HR
     HIGHER HEATING VALUE OF ASH = 1417. BTU/LB

     ULTIMATE ANALYSIS OF ASH
      (PERCENT OF DRY WEIGHT)
     CARBON.......    4.60
     HYDROGEN.....    0.00
     OXYGEN.......    0.00
     NITROGEN.....    0.00
     OTHER........   95.40

     OIL FLOW TO PRIMARY COMBUSTION CHAMBER =     0. LB/HR
     OIL FLOW TO SECONDARY COMBUSTION CHAMBER =  314. LB/HR
     HIGHER HEATING VALUE OF OIL = 19700. BTU/LB

     ULTIMATE ANALYSIS OF OIL
      (PERCENT OF DRY WEIGHT)
     CARBON.......   86.00
     HYDROGEN.....   12.00
     OXYGEN.......     .50
     NITROGEN.....    0.00
     OTHER........    1.50

     COMBUSTION AIR
       TO PRIMARY COMBUSTION CHAMBER (UNDERFIRE) =  243. LB/MIN
       TO PRIMARY COMBUSTION CHAMBER (OVERFIRE) =  237. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =     0. LB/MIN
       TO (WITH) PRIMARY OIL BURNER =    0. LB/MIN
       TO (WITH) SECONDARY OIL BURNER =   88. LB/MIN

     LEAKAGE AIR
       TO PRIMARY COMBUSTION CHAMBER =   0. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =   0. LB/MIN
       DOWN THE DUMP STACK =   0. LB/MIN

     AMBIENT AIR TEMPERATURE =  80. DEGF
```

HEAT TRANSFER PARAMETERS

SURFACE AREA OF FLAME FRONT = 135. SQFT
SURFACE AREA OF PCC = 1183. SQFT
SURFACE AREA OF SCC = 2094. SQFT
EMISSIVITY OF OUTER SURFACE OF INCINERATOR = .75

CONVECTION FILM COEFFICIENTS
INNER SURFACE OF PCC = 50. BTU/HR-SQFT-DEGF
INNER SURFACE OF SCC = 50. BTU/HR-SQFT-DEGF
OUTER SURFACE OF INCINERATOR = 1. BTU/HR-SQFT-DEGF
THERMAL CONDUCTANCE THRU WALLS
OF PRIMARY COMBUSTION CHAMBER = .250 BTU/HR-SQFT-DEGF
OF SECONDARY COMBUSTION CHAMBER = .250 BTU/HR-SQFT-DEGF
MEAN BEAM LENGTH
OF PRIMARY COMBUSTION CHAMBER = 5.30 FT
OF SECONDARY COMBUSTION CHAMBER = 5.30 FT

HRI HAS A CONVECTION TYPE BOILER AT THE SCC EXIT

CONVECTION BOILER CHARACTERISTICS

SURFACE AREA OF TUBES = 4426. SQFT
FEED WATER PROPERTIES
TEMPERATURE = 180. DEGF
ENTHALPY = 148. BTU/LB
STEAM PROPERTIES
TEMPERATURE = 370. DEGF
PRESSURE = 172. PSIA
ENTHALPY = 1196. BTU/LB (VAPOR)
ENTHALPY = 342. BTU/LB (LIQUID)
BOILER BLOW-DOWN = 10.0 PERCENT OF STEAM GENERATED
OVERALL HEAT TRANSFER COEFFICIENT = 4.05 BTU/HR-SQFT-DEGF AT THE DESIGN POINT

AIR REQUIRED FOR STOICHIOMETRIC COMBUSTION OF SOLID WASTE = 129.03 LB/MIN
HEAT ABSORBED IN BREAKING DOWN FUEL = -1747. BTU/LB

PRODUCTS OF COMBUSTION OF SOLID WASTE WITH STOICHIOMETRIC AIR
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.4186
WATER VAPOR.......	.7959
CARBON MONOXIDE...	0.0000
OXYGEN............	0.0000
NITROGEN..........	3.8562
HYDROGEN..........	0.0000
CARBON............	0.0000

FUEL (WASTE) MASS FEED RATE = 1543. LB/HR DRY
HEAT RELEASED IN FLAME ZONE = .6162E+04 BTU/LB OF DRY FUEL
HEAT LOST VAPORIZING THE MOISTURE IN THE FUEL = .3252E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU THE FLAME = .1615E+05 LB/HR
THEORETICAL (ADIABATIC) FLAME TEMPERATURE = 2010. DEGF

PRODUCTS OF COMBUSTION OF SOLID WASTE IN FLAME ZONE
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3647
WATER VAPOR.......	.7959
CARBON MONOXIDE...	0.0000
OXYGEN............	1.0568
NITROGEN..........	7.2041
HYDROGEN..........	0.0000
CARBON............	0.0000

HOMOGENEOUS FLAME TEMPERATURE = 1568. DEGF

HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER = .2910E-10 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU PRIMARY COMBUSTION CHAMBER = .3037E+05 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN PRIMARY COMBUSTION CHAMBER = 1163. DEGF
PRIMARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1185. DEGF
PRIMARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 197. DEGF

SPECIFIC HEAT OF PCC COMBUSTION PRODUCTS = .26 BTU/LB-DEGF
EMISSIVITY OF PCC COMBUSTION PRODUCTS = .249

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE PRIMARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3647
WATER VAPOR.......	.7959
CARBON MONOXIDE...	0.0000
OXYGEN............	3.1900
NITROGEN..........	14.2225
HYDROGEN..........	0.0000
CARBON............	0.0000

HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER = .3778E+04 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU SECONDARY COMBUSTION CHAMBER = .3596E+05 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN SECONDARY COMBUSTION CHAMBER = 1499. DEGF
SECONDARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1494. DEGF
SECONDARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 224. DEGF

SPECIFIC HEAT OF SCC COMBUSTION PRODUCTS = .27 BTU/LB-DEGF
EMISSIVITY OF SCC COMBUSTION PRODUCTS = .239

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE SECONDARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	2.0065
WATER VAPOR.......	1.0157
CARBON MONOXIDE...	0.0000
OXYGEN............	3.3211
NITROGEN..........	16.8284
HYDROGEN..........	0.0000
CARBON............	0.0000

```
TOTAL GAS FLOW OUT THE STACK =  .3596E+05 LB/HR
TEMPERATURE OF COMBUSTION GASES ENTERING THE BOILER = 1499. DEGF
STACK GAS TEMPERATURE =  509. DEGF

COMPOSITION OF STACK GASES
     (LBS/LB OF DRY FUEL)
CARBON DIOXIDE....     2.0065
WATER VAPOR.......     1.0157
CARBON MONOXIDE...     0.0000
OXYGEN............     3.3211
NITROGEN..........    16.8284
HYDROGEN..........     0.0000
CARBON............     0.0000

CONVECTION BOILER

     STEAM GENERATION =  8657. LB/HR

     BOILER HEAT TRANSFER RATE =  .9980E+07 BTU/HR
     BOILER OVERALL HEAT TRANSFER COEFFICIENT =    3.47 BTU/HR-SQFT-DEGF

     THERMAL EFFICIENCY OF BOILER =  .66


OVERALL EFFICIENCY OF HEAT RECOVERY INCINERATOR

     USING THE DIRECT METHOD

        INPUT =  .1058E+08 BTU/HR OF WASTE (HHV*DRY FEED RATE)
              +  .6186E+07 BTU/HR OF OIL (HHV*FLOW RATE)
              +  .2001E+07 BTU/HR FROM MISCELLANEOUS ACCESSORIES
        OUTPUT =  .9072E+07 BTU/HR TO STEAM

        EFFICIENCY = OUTPUT/INPUT =  .48

     USING THE SUMMATION OF LOSSES METHOD
```

INPUT	BTU/HR	FRACTION OF TOTAL INPUT
CHEMICAL + SENSIBLE ENERGY OF WASTE FUEL.....	.1058E+08	.5272
ENTHALPY OF COMBUSTION AIR...................	.1636E+06	.0081
CHEMICAL + SENSIBLE ENERGY OF OIL...........	.6186E+07	.3081
ENTHALPY OF BOILER FEED WATER................	.1142E+07	.0569
POWER REQUIRED TO RUN ACCESSORIES............	.2001E+07	.0997
TOTAL INPUT TO HRI SYSTEM....................	.2008E+08	

LOSSES	BTU/HR	FRACTION OF TOTAL INPUT
VAPORIZATION OF MOISTURE WITH WASTE..........	.5017E+06	.0250
VAPOR. OF H2O GEN. BY BURNING H2 IN WASTE....	.1019E+07	.0508
CARBON CARRIED OUT WITH ASH..................	.3197E+06	.0159
SENSIBLE HEAT IN ASH.........................	.1487E+06	.0074
HEAT TRANSFER THRU WALLS OF PCC..............	.2923E+06	.0146
HEAT TRANSFER THRU WALLS OF SCC..............	.6644E+06	.0331
INCOMPLETE COMBUSTION........................	0.	0.0000
SENSIBLE HEAT IN STACK GASES.................	.4080E+07	.2032
LOSS OF STEAM DUE TO BLOW-DOWN...............	.1123E+07	.0560
POWER REQUIRED TO RUN ACCESSORIES............	.2001E+07	.0997
TOTAL LOSSES FROM HRI SYSTEM.................	.1015E+08	.5056

EFFICIENCY = 1.-(TOTAL LOSSES)/(TOTAL INPUT) = .49

Naval Air Station, Jacksonville, Fla.

This is a dual combustion chamber device with a water tube boiler located downstream from the second combustion chamber. The incinerator shown in Figure 1, without the waterwalls, is the Jacksonville incinerator.

The average of the acceptance tests of 31 Oct 1979 (Ref 16) is duplicated. These tests provide a new example because the incinerator is starved; air supplied to the primary chamber is not sufficient for the complete combustion of the waste.

Input:

2300.	8957.						
47.56	6.22	43.84	0.09	2.29			
20.00	77.90	0.46	1.64				
200.	1417.						
5.	0.	0.	0.	95.			
5.	15.5	19700.					
86.	12.	0.5	0.	1.5			
100.							
50.	0.	410.	0.	12.			
10.	0.	10.					
112.	488.	360.	50.	50.	5.	0.75	0.75
70.	0.75	4.7	3.9				
2							
967.61	227.	195.	353.	1193.	325.	140.	0.02
9.24	1800.	500.	1.7E4				

Output:

FEED RATES AND BOUNDARY CONDITIONS

FUEL (WASTE) MASS FEED RATE = 2300. LB/HR WET
HIGHER HEATING VALUE OF FUEL = 8957. BTU/LB DRY

ULTIMATE ANALYSIS OF FUEL (PERCENT OF DRY WEIGHT)		PROXIMATE ANALYSIS OF FUEL (PERCENT OF WEIGHT)	
CARBON.......	47.56	MOISTURE.........	20.00
HYDROGEN.....	6.22	VOLATILE MATTER..	77.90
OXYGEN.......	43.84	FIXED CARBON.....	.46
NITROGEN.....	.09	ASH..............	1.64
OTHER........	2.29		

ASH REMOVAL RATE = 200. LB/HR
HIGHER HEATING VALUE OF ASH = 1417. BTU/LB

ULTIMATE ANALYSIS OF ASH
(PERCENT OF DRY WEIGHT)

CARBON.......	5.00
HYDROGEN.....	0.00
OXYGEN.......	0.00
NITROGEN.....	0.00
OTHER........	95.00

OIL FLOW TO PRIMARY COMBUSTION CHAMBER = 5. LB/HR
OIL FLOW TO SECONDARY COMBUSTION CHAMBER = 16. LB/HR
HIGHER HEATING VALUE OF OIL = 19700. BTU/LB

ULTIMATE ANALYSIS OF OIL
(PERCENT OF DRY WEIGHT)

CARBON.......	86.00
HYDROGEN.....	12.00
OXYGEN.......	.50
NITROGEN.....	0.00
OTHER........	1.50

COMBUSTION AIR
TO PRIMARY COMBUSTION CHAMBER (UNDERFIRE) = 50. LB/MIN
TO PRIMARY COMBUSTION CHAMBER (OVERFIRE) = 0. LB/MIN
TO SECONDARY COMBUSTION CHAMBER = 410. LB/MIN
TO (WITH) PRIMARY OIL BURNER = 0. LB/MIN
TO (WITH) SECONDARY OIL BURNER = 12. LB/MIN

LEAKAGE AIR
TO PRIMARY COMBUSTION CHAMBER = 10. LB/MIN
TO SECONDARY COMBUSTION CHAMBER = 0. LB/MIN
DOWN THE DUMP STACK = 10. LB/MIN

AMBIENT AIR TEMPERATURE = 70. DEGF

HEAT TRANSFER PARAMETERS
SURFACE AREA OF FLAME FRONT = 112. SQFT
SURFACE AREA OF PCC = 488. SQFT
SURFACE AREA OF SCC = 360. SQFT
EMISSIVITY OF OUTER SURFACE OF INCINERATOR = .75

CONVECTION FILM COEFFICIENTS
INNER SURFACE OF PCC = 50. BTU/HR-SQFT-DEGF
INNER SURFACE OF SCC = 50. BTU/HR-SQFT-DEGF
OUTER SURFACE OF INCINERATOR = 5. BTU/HR-SQFT-DEGF
THERMAL CONDUCTANCE THRU WALLS
OF PRIMARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
OF SECONDARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
MEAN BEAM LENGTH
OF PRIMARY COMBUSTION CHAMBER = 4.70 FT
OF SECONDARY COMBUSTION CHAMBER = 3.90 FT

HRI HAS A CONVECTION TYPE BOILER AT THE SCC EXIT

CONVECTION BOILER CHARACTERISTICS
SURFACE AREA OF TUBES = 968. SQFT
FEED WATER PROPERTIES
TEMPERATURE = 227. DEGF
ENTHALPY = 195. BTU/LB
STEAM PROPERTIES
TEMPERATURE = 353. DEGF
PRESSURE = 140. PSIA
ENTHALPY = 1193. BTU/LB (VAPOR)
ENTHALPY = 325. BTU/LB (LIQUID)
BOILER BLOW-DOWN = 2.0 PERCENT OF STEAM GENERATED
OVERALL HEAT TRANSFER COEFFICIENT = 9.24 BTU/HR-SQFT-DEGF AT THE DESIGN POINT

AIR REQUIRED FOR STOICHIOMETRIC COMBUSTION OF SOLID WASTE = 174.64 LB/MIN
HEAT ABSORBED IN BREAKING DOWN FUEL = -1570. BTU/LB

PRODUCTS OF COMBUSTION OF SOLID WASTE WITH STOICHIOMETRIC AIR
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.7439
WATER VAPOR.......	.8098
CARBON MONOXIDE...	0.0000
OXYGEN............	0.0000
NITROGEN..........	4.3683
HYDROGEN..........	0.0000
CARBON............	0.0000

FUEL (WASTE) MASS FEED RATE = 1840. LB/HR DRY
HEAT RELEASED IN FLAME ZONE = .1670E+04 BTU/LB OF DRY FUEL
HEAT LOST VAPORIZING THE MOISTURE IN THE FUEL = .2426E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU THE FLAME = .5100E+04 LB/HR
THEORETICAL (ADIABATIC) FLAME TEMPERATURE = 1550. DEGF

PRODUCTS OF COMBUSTION OF SOLID WASTE IN FLAME ZONE

(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	0.0000
WATER VAPOR.......	.5108
CARBON MONOXIDE...	1.0220
OXYGEN............	0.0000
NITROGEN..........	1.2425
HYDROGEN..........	.0332
CARBON............	.0322

HOMOGENEOUS FLAME TEMPERATURE = 1517. DEGF

HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER = .3377E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU PRIMARY COMBUSTION CHAMBER = .5705E+04 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN PRIMARY COMBUSTION CHAMBER = 1515. DEGF
PRIMARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1502. DEGF
PRIMARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 225. DEGF

SPECIFIC HEAT OF PCC COMBUSTION PRODUCTS = .34 BTU/LB-DEGF
EMISSIVITY OF PCC COMBUSTION PRODUCTS = .349

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE PRIMARY COMBUSTION CHAMBER

(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	.0220
WATER VAPOR.......	.5349
CARBON MONOXIDE...	1.0885
OXYGEN............	0.0000
NITROGEN..........	1.4908
HYDROGEN..........	.0309
CARBON............	0.0000

HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER = .6491E+04 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU SECONDARY COMBUSTION CHAMBER = .3104E+05 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN SECONDARY COMBUSTION CHAMBER = 1736. DEGF
SECONDARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 1718. DEGF
SECONDARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 247. DEGF

SPECIFIC HEAT OF SCC COMBUSTION PRODUCTS = .28 BTU/LB-DEGF
EMISSIVITY OF SCC COMBUSTION PRODUCTS = .204

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE SECONDARY COMBUSTION CHAMBER

(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.7591
WATER VAPOR.......	.8218
CARBON MONOXIDE...	0.0000
OXYGEN............	2.2889
NITROGEN..........	11.9701
HYDROGEN..........	0.0000
CARBON............	0.0000

TOTAL GAS FLOW OUT THE STACK = .3164E+05 LB/HR
TEMPERATURE OF COMBUSTION GASES ENTERING THE BOILER = 1708. DEGF
STACK GAS TEMPERATURE = 609. DEGF

COMPOSITION OF STACK GASES
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.7591
WATER VAPOR.......	.8218
CARBON MONOXIDE...	0.0000
OXYGEN............	2.3644
NITROGEN..........	12.2184
HYDROGEN..........	0.0000
CARBON............	0.0000

CONVECTION BOILER

STEAM GENERATION = 9804. LB/HR

BOILER HEAT TRANSFER RATE = .9980E+07 BTU/HR
BOILER OVERALL HEAT TRANSFER COEFFICIENT = 13.43 BTU/HR-SQFT-DEGF

THERMAL EFFICIENCY OF BOILER = .71

OVERALL EFFICIENCY OF HEAT RECOVERY INCINERATOR

USING THE DIRECT METHOD

INPUT = .1648E+08 BTU/HR OF WASTE (HHV*DRY FEED RATE)
+ .4039E+06 BTU/HR OF OIL (HHV*FLOW RATE)
+ .3415E+06 BTU/HR FROM MISCELLANEOUS ACCESSORIES
OUTPUT = .9785E+07 BTU/HR TO STEAM

EFFICIENCY = OUTPUT/INPUT = .57

USING THE SUMMATION OF LOSSES METHOD

INPUT	BTU/HR	FRACTION OF TOTAL INPUT
CHEMICAL + SENSIBLE ENERGY OF WASTE FUEL.....	.1649E+08	.8690
ENTHALPY OF COMBUSTION AIR...................	.7085E+05	.0037
CHEMICAL + SENSIBLE ENERGY OF OIL............	.4039E+06	.0213
ENTHALPY OF BOILER FEED WATER................	.1669E+07	.0880
POWER REQUIRED TO RUN ACCESSORIES............	.3415E+06	.0180
TOTAL INPUT TO HRI SYSTEM....................	.1897E+08	

LOSSES	BTU/HR	FRACTION OF TOTAL INPUT
VAPORIZATION OF MOISTURE WITH WASTE..........	.4463E+06	.0235
VAPOR. OF H2O GEN. BY BURNING H2 IN WASTE....	.1021E+07	.0538
CARBON CARRIED OUT WITH ASH.................	.1410E+06	.0074
SENSIBLE HEAT IN ASH........................	.5828E+05	.0031
HEAT TRANSFER THRU WALLS OF PCC.............	.4674E+06	.0246
HEAT TRANSFER THRU WALLS OF SCC.............	.3972E+06	.0209
INCOMPLETE COMBUSTION.......................	0.	0.0000
SENSIBLE HEAT IN STACK GASES................	.4426E+07	.2333
LOSS OF STEAM DUE TO BLOW-DOWN..............	.2331E+06	.0123
POWER REQUIRED TO RUN ACCESSORIES...........	.3415E+06	.0180
TOTAL LOSSES FROM HRI SYSTEM................	.7532E+07	.3970

EFFICIENCY = 1.-(TOTAL LOSSES)/(TOTAL INPUT) = .60

Besancon, France, Unit No. 3 (Ref 17)

This example illustrates the potential of the model to simulate waterwalls. As shown in Figure 9, the waterwalls do not "see" the flame; for purposes of modeling, they are considered to be in a secondary chamber. The device also has a convection type heat exchanger.

Input:

6000.	6200.						
37.29	4.99	32.11	0.46	25.15			
20.00	52.70	7.30	20.00				
630.	1417.						
5.	0.	0.	0.	95.			
0.	0.	19700.					
86.	12.	0.5	0.	1.5			
85.23							
430.	230.	0.	0.	0.			
0.	0.	0.					
126.	677.	75.	50.	50.	5.	0.75	0.75
70.	0.75	4.9	4.2				
6							
1200.	194.	162.	482.	1236.	416.	368.	0.02
9.	1800.	500.	1.7E4				
482.	368.	1236.	194.	162.	0.02		

Output:

FEED RATES AND BOUNDARY CONDITIONS

```
     FUEL (WASTE) MASS FEED RATE =  6000. LB/HR WET
     HIGHER HEATING VALUE OF FUEL =  6200. BTU/LB DRY

     ULTIMATE ANALYSIS OF FUEL                     PROXIMATE ANALYSIS OF FUEL
      (PERCENT OF DRY WEIGHT)                          (PERCENT OF WEIGHT)
     CARBON.......   37.29                         MOISTURE.........   20.00
     HYDROGEN.....    4.99                         VOLATILE MATTER..   52.70
     OXYGEN.......   32.11                         FIXED CARBON.....    7.30
     NITROGEN.....     .46                         ASH..............   20.00
     OTHER........   25.15

     ASH REMOVAL RATE =  630. LB/HR
     HIGHER HEATING VALUE OF ASH = 1417. BTU/LB

     ULTIMATE ANALYSIS OF ASH
      (PERCENT OF DRY WEIGHT)
     CARBON.......    5.00
     HYDROGEN.....    0.00
     OXYGEN.......    0.00
     NITROGEN.....    0.00
     OTHER........   95.00

     OIL FLOW TO PRIMARY COMBUSTION CHAMBER =     0. LB/HR
     OIL FLOW TO SECONDARY COMBUSTION CHAMBER =     0. LB/HR
     HIGHER HEATING VALUE OF OIL = 19700. BTU/LB

     ULTIMATE ANALYSIS OF OIL
      (PERCENT OF DRY WEIGHT)
     CARBON.......   86.00
     HYDROGEN.....   12.00
     OXYGEN.......     .50
     NITROGEN.....    0.00
     OTHER........    1.50

     COMBUSTION AIR
       TO PRIMARY COMBUSTION CHAMBER (UNDERFIRE) =  430. LB/MIN
       TO PRIMARY COMBUSTION CHAMBER (OVERFIRE) =  230. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =     0. LB/MIN
       TO (WITH) PRIMARY OIL BURNER =     0. LB/MIN
       TO (WITH) SECONDARY OIL BURNER =     0. LB/MIN

     LEAKAGE AIR
       TO PRIMARY COMBUSTION CHAMBER =    0. LB/MIN
       TO SECONDARY COMBUSTION CHAMBER =    0. LB/MIN
       DOWN THE DUMP STACK =    0. LB/MIN

     AMBIENT AIR TEMPERATURE =  70. DEGF
```

HEAT TRANSFER PARAMETERS
    SURFACE AREA OF FLAME FRONT = 126. SQFT
    SURFACE AREA OF PCC = 677. SQFT
    SURFACE AREA OF SCC = 75. SQFT
    EMISSIVITY OF OUTER SURFACE OF INCINERATOR = .75

    CONVECTION FILM COEFFICIENTS
      INNER SURFACE OF PCC = 50. BTU/HR-SQFT-DEGF
      INNER SURFACE OF SCC = 50. BTU/HR-SQFT-DEGF
      OUTER SURFACE OF INCINERATOR = 5. BTU/HR-SQFT-DEGF
    THERMAL CONDUCTANCE THRU WALLS
      OF PRIMARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
      OF SECONDARY COMBUSTION CHAMBER = .750 BTU/HR-SQFT-DEGF
    MEAN BEAM LENGTH
      OF PRIMARY COMBUSTION CHAMBER = 4.90 FT
      OF SECONDARY COMBUSTION CHAMBER = 4.20 FT

HRI HAS BOTH A SCC WATER-WALL AND CONVECTION TYPE BOILER

CONVECTION BOILER CHARACTERISTICS
    SURFACE AREA OF TUBES = 1200. SQFT
    FEED WATER PROPERTIES
      TEMPERATURE = 194. DEGF
      ENTHALPY = 162. BTU/LB
    STEAM PROPERTIES
      TEMPERATURE = 482. DEGF
      PRESSURE = 368. PSIA
      ENTHALPY = 1236. BTU/LB (VAPOR)
      ENTHALPY = 416. BTU/LB (LIQUID)
    BOILER BLOW-DOWN = 2.0 PERCENT OF STEAM GENERATED
    OVERALL HEAT TRANSFER COEFFICIENT = 9.00 BTU/HR-SQFT-DEGF AT THE DESIGN POINT

SECONDARY COMBUSTION CHAMBER WATER-WALL BOILER CHARACTERISTICS
    SURFACE AREA OF WATER-WALL = 75. SQFT
    FEED WATER PROPERTIES
      TEMPERATURE = 194. DEGF
      EHTHALPY = 162. BTU/LB
    STEAM PROPERTIES
      TEMPERATURE = 482. DEGF
      PRESSURE = 368. PSIA
      ENTHALPY = 1236. BTU/LB
    BOILER BLOW-DOWN = 2.0 PERCENT OF STEAM GENERATED

AIR REQUIRED FOR STOICHIOMETRIC COMBUSTION OF SOLID WASTE = 368.08 LB/MIN
HEAT ABSORBED IN BREAKING DOWN FUEL = -2123. BTU/LB

PRODUCTS OF COMBUSTION OF SOLID WASTE WITH STOICHIOMETRIC AIR
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3673
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	0.0000
NITROGEN..........	3.5331
HYDROGEN..........	0.0000
CARBON............	0.0000

FUEL (WASTE) MASS FEED RATE = 4800. LB/HR DRY
HEAT RELEASED IN FLAME ZONE = .5635E+04 BTU/LB OF DRY FUEL
HEAT LOST VAPORIZING THE MOISTURE IN THE FUEL = .2426E+03 BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU THE FLAME = .3117E+05 LB/HR
THEORETICAL (ADIABATIC) FLAME TEMPERATURE = 2747. DEGF

PRODUCTS OF COMBUSTION OF SOLID WASTE IN FLAME ZONE
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3432
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.1891
NITROGEN..........	4.0978
HYDROGEN..........	0.0000
CARBON............	0.0000

HOMOGENEOUS FLAME TEMPERATURE = 2324. DEGF

HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER = 0. BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU PRIMARY COMBUSTION CHAMBER = .4497E+05 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN PRIMARY COMBUSTION CHAMBER = 1994. DEGF
PRIMARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 2052. DEGF
PRIMARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 279. DEGF

SPECIFIC HEAT OF PCC COMBUSTION PRODUCTS = .29 BTU/LB-DEGF
EMISSIVITY OF PCC COMBUSTION PRODUCTS = .252

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE PRIMARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3432
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.8546
NITROGEN..........	6.2872
HYDROGEN..........	0.0000
CARBON............	0.0000

HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER = 0. BTU/LB OF DRY FUEL
TOTAL GAS FLOW THRU SECONDARY COMBUSTION CHAMBER = .4497E+05 LB/HR
HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN SECONDARY COMBUSTION CHAMBER = 1642. DEGF
SECONDARY COMBUSTION CHAMBER INSIDE WALL TEMPERATURE = 482. DEGF
SECONDARY COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = 117. DEGF

SPECIFIC HEAT OF SCC COMBUSTION PRODUCTS = .28 BTU/LB-DEGF
EMISSIVITY OF SCC COMBUSTION PRODUCTS = .267

PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN THE SECONDARY COMBUSTION CHAMBER
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3432
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.8546
NITROGEN..........	6.2872
HYDROGEN..........	0.0000
CARBON............	0.0000

TOTAL GAS FLOW OUT THE STACK = .4497E+05 LB/HR
TEMPERATURE OF COMBUSTION GASES ENTERING THE BOILER = 1642. DEGF
STACK GAS TEMPERATURE = 597. DEGF

COMPOSITION OF STACK GASES
(LBS/LB OF DRY FUEL)

CARBON DIOXIDE....	1.3432
WATER VAPOR.......	.6991
CARBON MONOXIDE...	0.0000
OXYGEN............	.8546
NITROGEN..........	6.2872
HYDROGEN..........	0.0000
CARBON............	0.0000

CONVECTION BOILER

STEAM GENERATION = 12614. LB/HR

BOILER HEAT TRANSFER RATE = .1382E+08 BTU/HR
BOILER OVERALL HEAT TRANSFER COEFFICIENT = 16.08 BTU/HR-SQFT-DEGF

THERMAL EFFICIENCY OF BOILER = .70

SECONDARY COMBUSTION CHAMBER WATER-WALL BOILER

STEAM GENERATION = 4621. LB/HR

TOTAL HEAT TRANSFERRED TO WALLS = .4984E+07 BTU/HR
BY CONVECTION FROM PRODUCTS OF COMBUSTION = .4349E+07 BTU/HR (87.3 PERCENT OF TOTAL)
BY RADIATION FROM PRODUCTS OF COMBUSTION = .6347E+06 BTU/HR (12.7 PERCENT OF TOTAL)
HEAT LOST BY CONDUCTION OUT THRU THE WALLS = .2055E+05 BTU/HR

THERMAL EFFICIENCY OF BOILER = .21

OVERALL EFFICIENCY OF HEAT RECOVERY INCINERATOR

USING THE DIRECT METHOD

INPUT = .2976E+08 BTU/HR OF WASTE (HHV*DRY FEED RATE)
+ 0. BTU/HR OF OIL (HHV*FLOW RATE)
+ .2911E+06 BTU/HR FROM MISCELLANEOUS ACCESSORIES
OUTPUT = .1851E+08 BTU/HR TO STEAM

EFFICIENCY = OUTPUT/INPUT = .62

USING THE SUMMATION OF LOSSES METHOD

INPUT	BTU/HR	FRACTION OF TOTAL INPUT
CHEMICAL + SENSIBLE ENERGY OF WASTE FUEL.....	.2977E+08	.9157
ENTHALPY OF COMBUSTION AIR..................	.9504E+05	.0029
CHEMICAL + SENSIBLE ENERGY OF OIL...........	0.	0.0000
ENTHALPY OF BOILER FEED WATER................	.2355E+07	.0724
POWER REQUIRED TO RUN ACCESSORIES...........	.2911E+06	.0090
TOTAL INPUT TO HRI SYSTEM....................	.3251E+08	

LOSSES	BTU/HR	FRACTION OF TOTAL INPUT
VAPORIZATION OF MOISTURE WITH WASTE..........	.1164E+07	.0358
VAPOR. OF H2O GEN. BY BURNING H2 IN WASTE....	.2092E+07	.0643
CARBON CARRIED OUT WITH ASH..................	.4441E+06	.0137
SENSIBLE HEAT IN ASH.........................	.2852E+06	.0088
HEAT TRANSFER THRU WALLS OF PCC..............	.9001E+06	.0277
HEAT TRANSFER THRU WALLS OF SCC..............	.2055E+05	.0006
INCOMPLETE COMBUSTION........................	0.	0.0000
SENSIBLE HEAT IN STACK GASES.................	.6298E+07	.1937
LOSS OF STEAM DUE TO BLOW-DOWN...............	.4249E+06	.0131
POWER REQUIRED TO RUN ACCESSORIES...........	.2911E+06	.0090
TOTAL LOSSES FROM HRI SYSTEM.................	.1192E+08	.3666

EFFICIENCY = 1.-(TOTAL LOSSES)/(TOTAL INPUT) = .63

PROGRAM LISTING

Included in this section are a list of the program variables, flow diagrams of the program and, finally, the complete FORTRAN listing.

Program Nomenclature

[* indicates inputs and data]

ABOIL*	Surface area of boiler tubes, ft^2
AFLAME*	Surface area of hearth covered by the flame, ft^2
AIR	Sum of all airflows entering the incinerator
AIROF*	Overfire air, lb/min
AIROIL(1)*	Air supplied to the oil burners in the PCC, lb/min
AIROIL(2)*	Air supplied to the oil burners in the SCC, lb/min
AIRPCC*	Underfire combustion air, lb/min
AIRSCC*	Combustion air supplied to the SCC, lb/min
APCC*	Surface area of PCC walls, ft^2
ASCC*	Surface area of SCC walls, ft^2
ASH*	Rate of ash removal, lb/hr
ASHE*	Ash content of waste via proximate analysis, % by weight
BD(I)*	Blowdown losses from the various boiler configurations, fraction of steam generated
C(1)*	Carbon content of waste via ultimate analysis, % of dry weight
C(2)*	Carbon content of ash, % of weight
C(3)*	Carbon content of oil used as an auxiliary fuel, % of weight
CARBON(1)	Elemental carbon in the fuel, moles/lb of waste
CARBON(2)	Carbon formed as a result of the incomplete combustion of the fuel, moles/lb of waste
CO	Accumulative carbon monoxide formed via combustion of the waste and oil, moles CO/lb of waste

COIL	Carbon content of oil, moles/lb of oil
CO2	Accumulative carbon dioxide formed via combustion of waste and oil, moles CO_2/lb of waste
CPF	Specific heat of combustion products in the flame, Btu/lb-°F
CPGAS	Specific heat of combustion products inside the boiler, Btu/lb-°F
CPOUT	Specific heat of combustion products if flame was adiabatic, Btu/lb-°F
CPP	Specific heat of combustion products inside PCC, Btu/lb-°F
CPS	Specific heat of combustion products inside SCC, Btu/lb-°F
D	Resultant determinate calculated in subroutine MINV
DCPF	Derivative of CPF with respect to temperature
DCPGAS	Derivative of CPGAS with respect to temperature
DCPP	Derivative of CPP with respect to temperature
DCPS	Derivative of CPS with respect to temperature
DEFLME	Derivative of EFLME with respect to temperature
DEPCC	Derivative of EPCC with respect to temperature
DESCC	Derivative of ESCC with respect to temperature
DEV	The change in the value of calculated temperatures from one iteration to the next
DEVMAX	Maximum value of DEV following an iteration for temperatures
DEVOLD	Value of DEV in the preceding iteration
DEWALL	Derivative of EWALL with respect to temperature
DFDT	Derivative of the function F(1) with respect to temperature
DKFDT	Derivative of KF with respect to temperature
DMUDT	Derivative of MU with respect to temperature

DSAVE	Value of DEVMAX in the preceding iteration
DUDT	Derivative of U with respect to temperature
EFF	Boiler or overall incinerator efficiency
EFLME	Emissivity of combustion products in the flame
EPCC	Emissivity of combustion products in the PCC
ESCC	Emissivity of combustion products in the SCC
ESHELL	Emissivity of the outer shell of the incinerator
EWALL	Emissivity of the walls of the PCC or SCC
F(I)	Functions used to define conservation of energy equations during Newton-Raphson iteration
FACTOR	Variable of convenience
FC*	Fixed carbon content of waste via proximate analysis, % by weight
FLOW	Flow rate of combustion gas through boiler at design point, lb/hr
FUEL*	Feed rate of waste; wet waste is input then later converted to a dry waste equivalent, lb/hr
F1-F25	Constants of convenience
GAS	Total mass flowing through the flame, both waste and combustion air, lb/hr
GASOUT	Total combustion gases flowing through the boiler, lb/hr
GASPCC	Total combustion gases flowing through PCC, lb/hr
GASSCC	Total combustion gas flowing through SCC, lb/hr
H(1)*	Hydrogen content of waste via ultimate analysis, % of dry weight
H(2)*	Hydrogen content of ash, % of weight
H(3)*	Hydrogen content of oil, % of weight
HCONV(1)*	Convective heat transfer coefficient of inner walls of PCC, Btu/hr-ft^2-°F

HCONV(2)*	Convective heat transfer coefficient of inner walls of SCC, Btu/hr-ft^2-°F
HCONV(3)*	Convective heat transfer coefficient of outer surface of incinerator, Btu/hr-ft^2-°F
HDATUM*	Enthalpy reference value, Btu/lb
HEVAP*	Enthalpy of feed water at saturation, Btu/lb
HFEED(I)*	Enthalpy of feed water as supplied to boilers, Btu/lb
HFG*	Heat of vaporization of moisture in the waste, Btu/lb
HHV(1)*	Higher heating value of waste, Btu/lb
HHV(2)*	Higher heating value of ash, Btu/lb
HHV(3)*	Higher heating value of oil, Btu/lb
HOIL	Elemental hydrogen content of oil, moles/lb of oil
HSTM(I)*	Enthalpy of the steam leaving the boilers, Btu/lb
HTCO*	Enthalpy of formation of carbon monoxide, Btu/mole
HTCOMB	Total energy released during combustion in the PCC and then in the SCC, Btu/lb of fuel
HTCO2*	Enthalpy of formation of carbon dioxide, Btu/mole
HTFLME	Net energy released during combustion in the flame zone, Btu/hr
HTFUEL	Energy absorbed/emitted in breaking down the fuel; in effect, a heat of pyrolysis, Btu/lb of fuel
HTH2O(1)*	Enthalpy of formation of water vapor, Btu/mole
HTH2O(2)*	Enthalpy of formation of water, Btu/mole
HTIN	Energy released to adiabatic flame, Btu/hr
HTLOST	Energy lost vaporizing the moisture in the waste, Btu/lb of waste
HTOIL	Energy absorbed/emitted in breaking down the oil, Btu/lb of oil entering PCC
HTOILP	Energy absorbed/emitted in breaking down the oil, Btu/lb of waste

HTOILS	Energy absorbed/emitted in breaking down the oil, Btu/lb of oil entering SCC
HTOTAL	Total water at a particular location, moles/lb of fuel
HTPCC	Total energy released to the PCC, Btu
HTSCC	Total energy released to the SCC, Btu
HYD	Elemental hydrogen arriving at a particular combustion zone, moles/lb of fuel
H2	Hydrogen gas formed as a result of the incomplete combustion of the fuel, moles/lb of fuel
H2O(1)	Moisture entering with the waste, moles/lb of waste
H2O(2)	Water vapor formed as a result of burning the hydrogen in the waste, moles/lb of waste
INPUT(1)	Chemical plus sensible energy of the waste, Btu/hr
INPUT(2)	Enthalpy of the combustion air, Btu/hr
INPUT(3)	Chemical plus sensible energy of the oil, Btu/hr
INPUT(4)	Enthalpy of boiler feed water, Btu/hr
INPUT(5)	Power required to run accessories, Btu/hr
ITER*	Maximum number of iterations allowed
JBOIL(I)	Jacobian of the energy equations governing the boiler
JPCC	Jacobian of the energy equations governing the PCC
JSCC	Jacobian of the energy equations governing the SCC
KF	Average thermal conductivity of combustion gases passing through the boiler
KW*	External power requirements of the incinerator, kW
KWALL(1)*	Effective thermal conductance through walls of PCC; thermal conductivity divided by thickness, Btu/hr-ft^2-°F
KWALL(2)*	Effective thermal conductance through walls of SCC, Btu/hr-ft^2-°F
LEAK(1)*	Air leakage into or out of the PCC, lb/min
LEAK(2)*	Air leakage into or out of the SCC, lb/min

LEAK(3)*	Air leakage down the dump stack, lb/min
LOSSES(1)	Loss due to vaporization of moisture with waste, Btu/hr
LOSSES(2)	Loss due to vaporization of moisture generated by burning hydrogen in the waste, Btu/hr
LOSSES(3)	Loss due to carbon carried out with the ash, Btu/hr
LOSSES(4)	Loss due to sensible heat in ash, Btu/hr
LOSSES(5)	Loss due to heat transfer out through walls of PCC, Btu/hr
LOSSES(6)	Loss due to heat transfer out through walls of SCC, Btu/hr
LOSSES(7)	Loss due to hydrogen and carbon monoxide in stack gases, Btu/hr
LOSSES(8)	Loss due to sensible heat in stack gases, Btu/hr
LOSSES(9)	Loss of steam to blowdown, Btu/hr
LPCC*	Mean beam length of the PCC, ft
LSCC*	Mean beam length of the SCC, ft
MUF	Average viscosity of combustion gases passing through the boiler
N(1)*	Nitrogen content of waste via ultimate analysis, % of dry weight
N(2)*	Nitrogen content of ash, % of weight
N(3)*	Nitrogen content of oil, % of weight
NIT	Elemental nitrogen arriving at a particular combustion zone, moles/lb of waste
NN	Number of energy equations involved in a particular iteration
N2	Amount of N_2 arriving at a particular location, moles/lb of waste
O(1)*	Oxygen content of waste via ultimate analysis, % of dry weight
O(2)*	Oxygen content of ash, % of weight
O(3)*	Oxygen content of oil, % of weight

OIL(1)*	Oil supplied to PCC burner, lb/hr
OIL(2)*	Oil supplied to SCC burner, lb/hr
OUTPUT	Energy of the steam generated in the boilers, Btu/hr
OXY	Elemental oxygen arriving at a particular combustion zone, moles/lb of waste
O2(1)	Amount of oxygen arriving at a particular combustion zone (i.e., flame, PCC, or SCC), moles/lb of waste
O2(2)	Amount of oxygen remaining after combustion in a particular zone, moles/lb of waste
P(I)	Products of combustion, lb/lb of waste
PSTM(I)*	Pressure of steam leaving the boilers, psia
QCOND	Heat conducted through walls of combustion chambers, Btu/hr
QCONV	Convection heat transfer from combustion gases to PCC or SCC waterwalls, Btu/hr
QFLAME	Gross energy released to the flame, Btu/lb of waste
QRAD1	Radiation from flame to PCC waterwalls, Btu/hr
QRAD2	Radiation from PCC or SCC combustion products to waterwalls, Btu/hr
QSTM	Heat transfer from combustion gases to steam, Btu/hr
QTOTAL	Total heat transferred to waterwalls, PCC or SCC, as applicable, Btu/hr
RATIO(I)	Percentages of convection and radiation heat transfer to waterwalls; later used to express inputs and losses as individual fractions
SAVE	Value of temperature in the preceding iteration
SIGMA*	Stefan-Boltzmann constant, Btu/hr-ft^2-$°R^4$
STEAM(1)	Steam generated in convection boiler, lb/hr
STEAM(2)	Steam generated by PCC waterwalls, lb/hr
STEAM(3)	Steam generated by SCC waterwalls, lb/hr
STOICH	Air required for stoichiometric combustion of solid waste, lb/min

T(I)	Temperature, as applicable, °R
TAMB*	Ambient air temperature, °F
TDATUM*	Reference temperature, °R
TFEED(I)*	Feed water temperature, °F
TFLAME(1)	Adiabatic flame temperature, °R
TFLAME(2)	Homogeneous flame temperature, °R
TIN	Design inlet temperature of convection boiler combustion gas, °F
TOL*	Iteration convergence tolerance, °F
TOTAL1	Total energy input to the incinerator, Btu/hr
TOTAL2	Total incinerator losses, Btu/hr
TOUT	Design exit temperature of convection boiler combustion gas, °F
TPCC	Temperature of combustion gases in PCC, °R
TSCC	Temperature of combustion gases in SCC, °R
TSHELL(I)	Temperature of the outer shell of the incinerator, °F
TSTACK	Actual temperature of combustion gas exiting boiler (i.e., gases going up the stack), °R
TSTM(I)	Temperature of steam leaving the boilers, °F
TWALL(1)	Temperature of the inside of the PCC walls, °F
TWALL(2)	Temperature of the inside of the SCC walls, °F
TYPE*	Code to designate the incinerator configuration
U	Convection boiler overall heat transfer coefficient, Btu/hr-ft^2-°F
UCONST	Constant of proportionality used in calculating U
VM*	Volatile matter in waste via proximate analysis, % by weight
WATER*	Moisture in waste via proximate analysis, % by weight
WVPL	Work vector used in subroutine MINV

WVPM	Work vector
WVSL	Work vector
WVSM	Work vector
X(I)*	Everything other than carbon, hydrogen, oxygen, and nitrogen as determined via ultimate analysis, % of dry weight

Subroutine Nomenclature

[When different from or not included in main program]

FUNCTION SPHT

CP(1)	Mean specific heat of oxygen between reference temperature and specified temperature, Btu/lb-°F
CP(2)	Mean specific heat of nitrogen
CP(3)	Mean specific heat of carbon monoxide
CP(4)	Mean specific heat of hydrogen
CP(5)	Mean specific heat of water vapor
CP(6)	Mean specific heat of carbon dioxide
DELTA	Temperature relative to reference temperature, °F
H2O	Water vapor in the gas mixture, moles/lb of waste
MOLES	Total number of moles in the gas mixture
MW	Molecular weight of the mixture

FUNCTION DCPDT

CP(I)	Derivatives of the mean specific heats of the components of a gaseous mixture with respect to its specified temperature

FUNCTION EMISS

DELTA	Emissivity correction to account for overlap of carbon dioxide and water vapor
ECO	Emissivity of the carbon monoxide in the gas mixture
ECO2	Emissivity of the carbon dioxide in the gas mixture

EH2O	Emissivity of the water vapor in the gas mixture
EMAX	Variable of convenience
L	Mean beam length, ft
PCO	Partial pressure of carbon monoxide in gas mixture, atmospheres
PCOL	Product of partial pressure of carbon monoxide and mean beam length
PCO2	Partial pressure of carbon dioxide in gas mixture, atmospheres
PCO2L	Product of partial pressure of carbon dioxide and mean beam length
PH2O	Partial pressure of water vapor in gas mixture, atmospheres
PH2OL	Product of partial pressure of water vapor and mean beam length
POWER	Variable of convenience
TMAX	Variable of convenience

FUNCTION DEDT

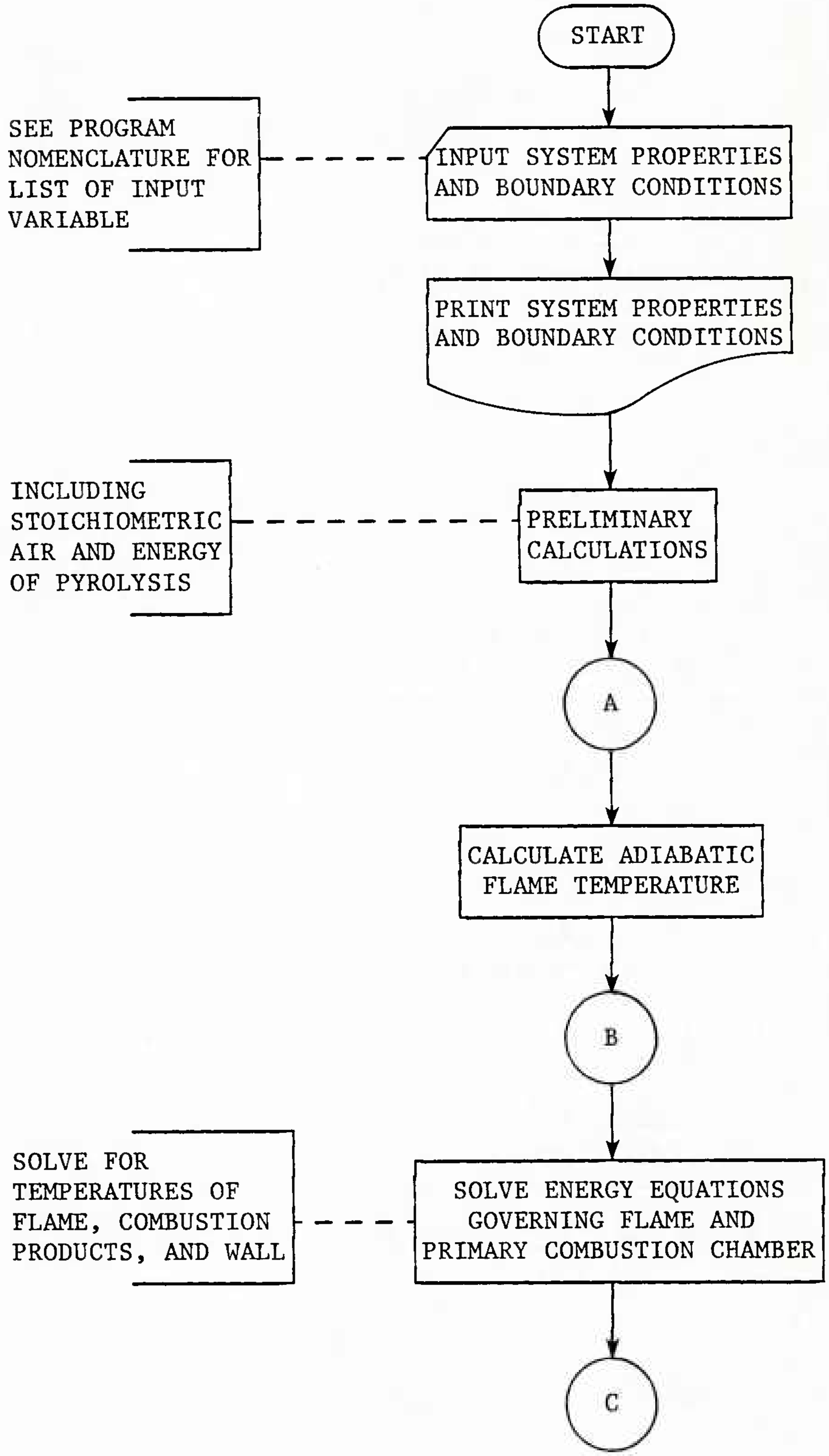
DDELDT	Correction of emissivity derivative to account for overlap of carbon dioxide and water vapor
DECO	Derivative of ECO with respect to temperature
DECO2	Derivative of ECO2 with respect to temperature
DEH2O	Derivative of EH2O with respect to temperature
POWER1	Variable of convenience

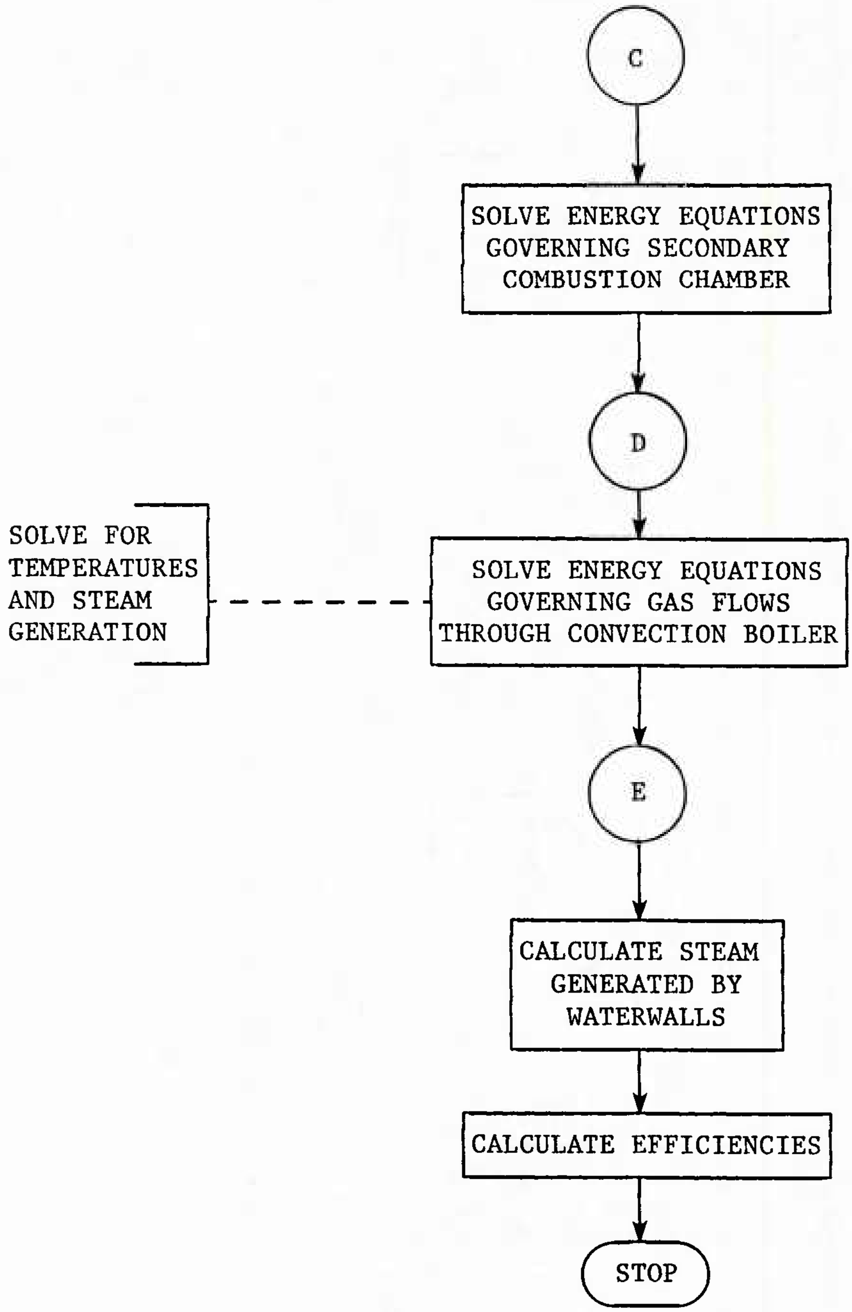
SUBROUTINE EQUATE

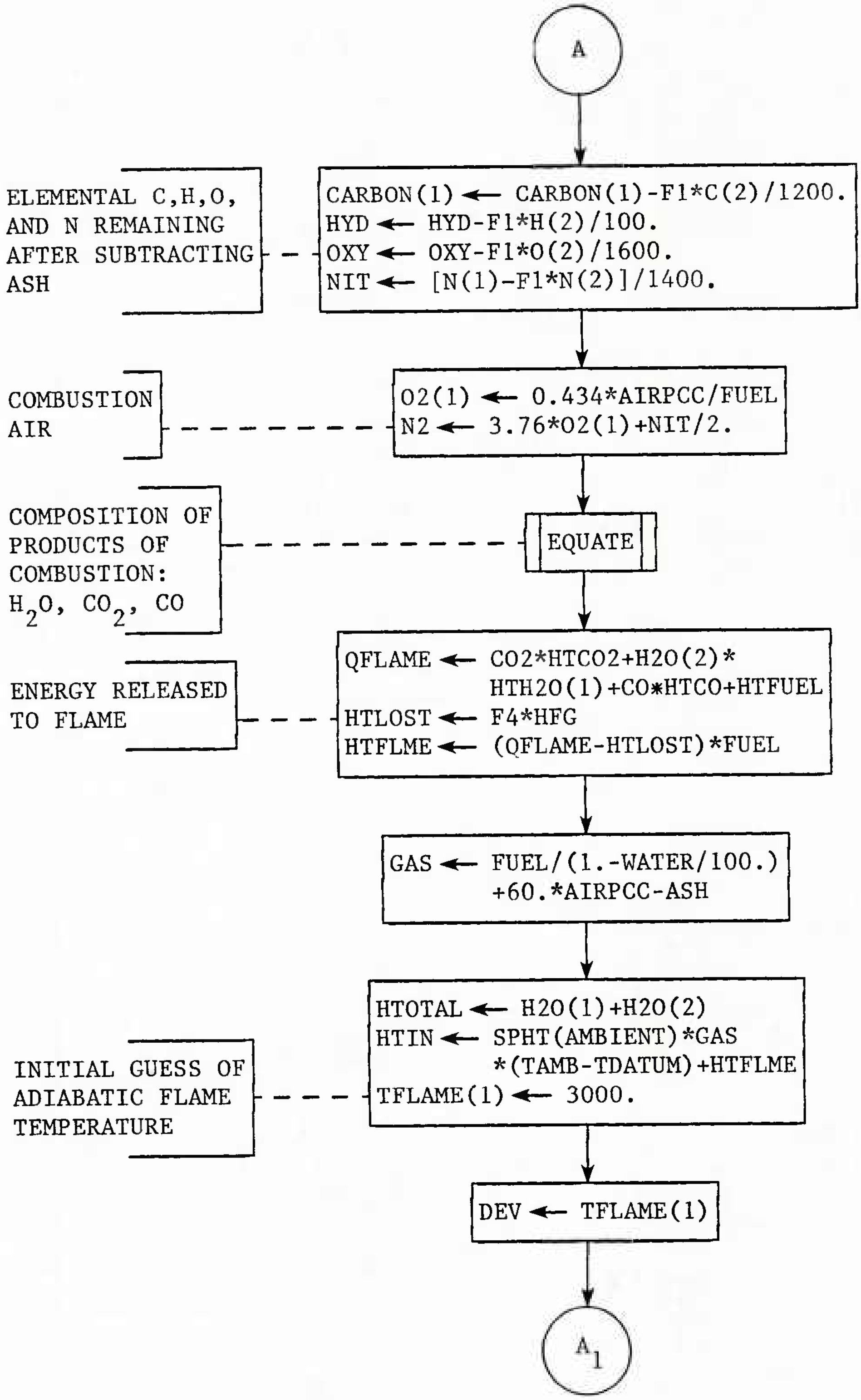
S	Elemental oxygen available for combustion
STOICH	Elemental oxygen required for complete combustion of the fuel
T	Variable of convenience

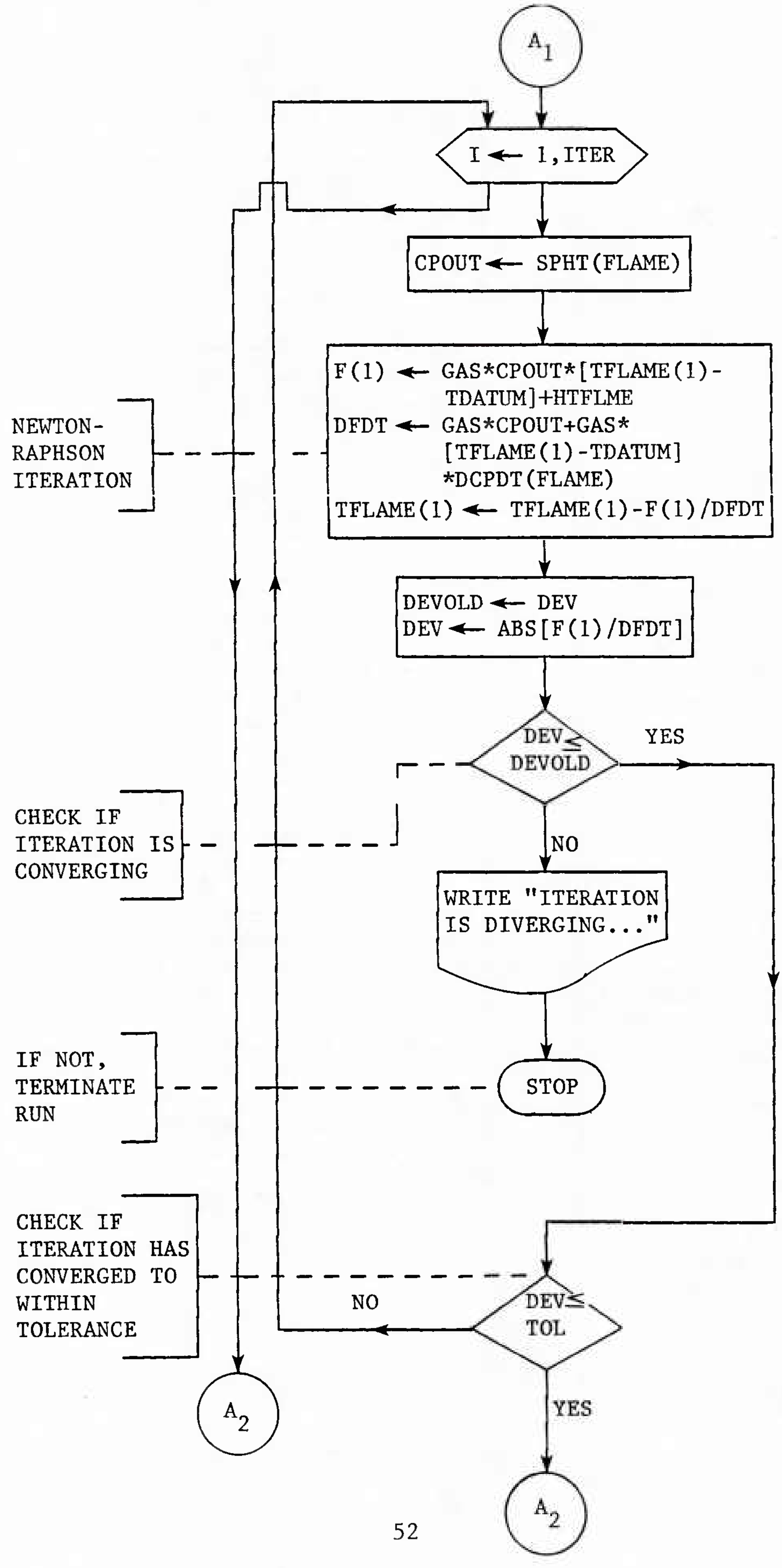
Flow Diagrams

Function DEDT is analogous to function EMISS and is not diagrammed. Subroutine MINV, a simple matrix inversion, is not diagrammed. Functions SPHT and DCPDT are trivial.

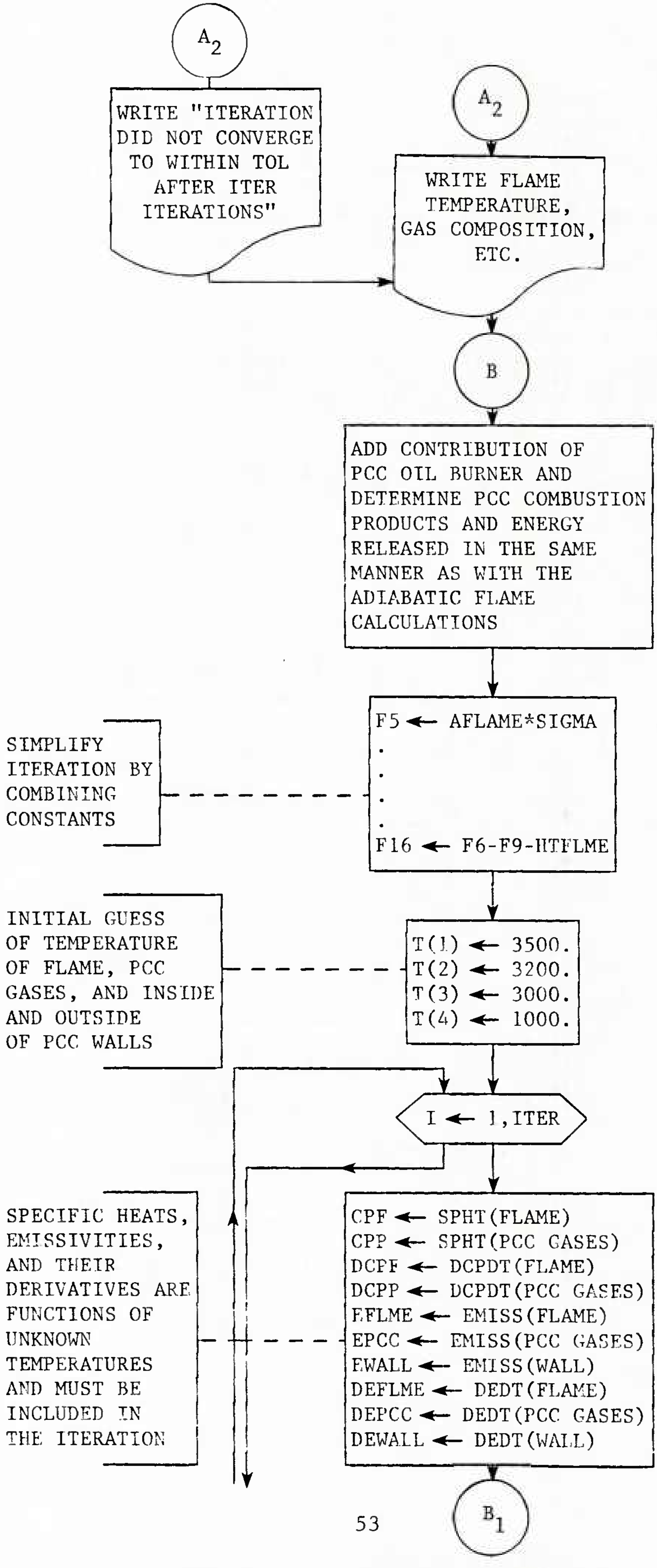

START
SEE PROGRAM NOMENCLATURE FOR LIST OF INPUT VARIABLE
INPUT SYSTEM PROPERTIES AND BOUNDARY CONDITIONS
PRINT SYSTEM PROPERTIES AND BOUNDARY CONDITIONS
INCLUDING STOICHIOMETRIC AIR AND ENERGY OF PYROLYSIS
PRELIMINARY CALCULATIONS
A
CALCULATE ADIABATIC FLAME TEMPERATURE
B
SOLVE FOR TEMPERATURES OF FLAME, COMBUSTION PRODUCTS, AND WALL
SOLVE ENERGY EQUATIONS GOVERNING FLAME AND PRIMARY COMBUSTION CHAMBER
C

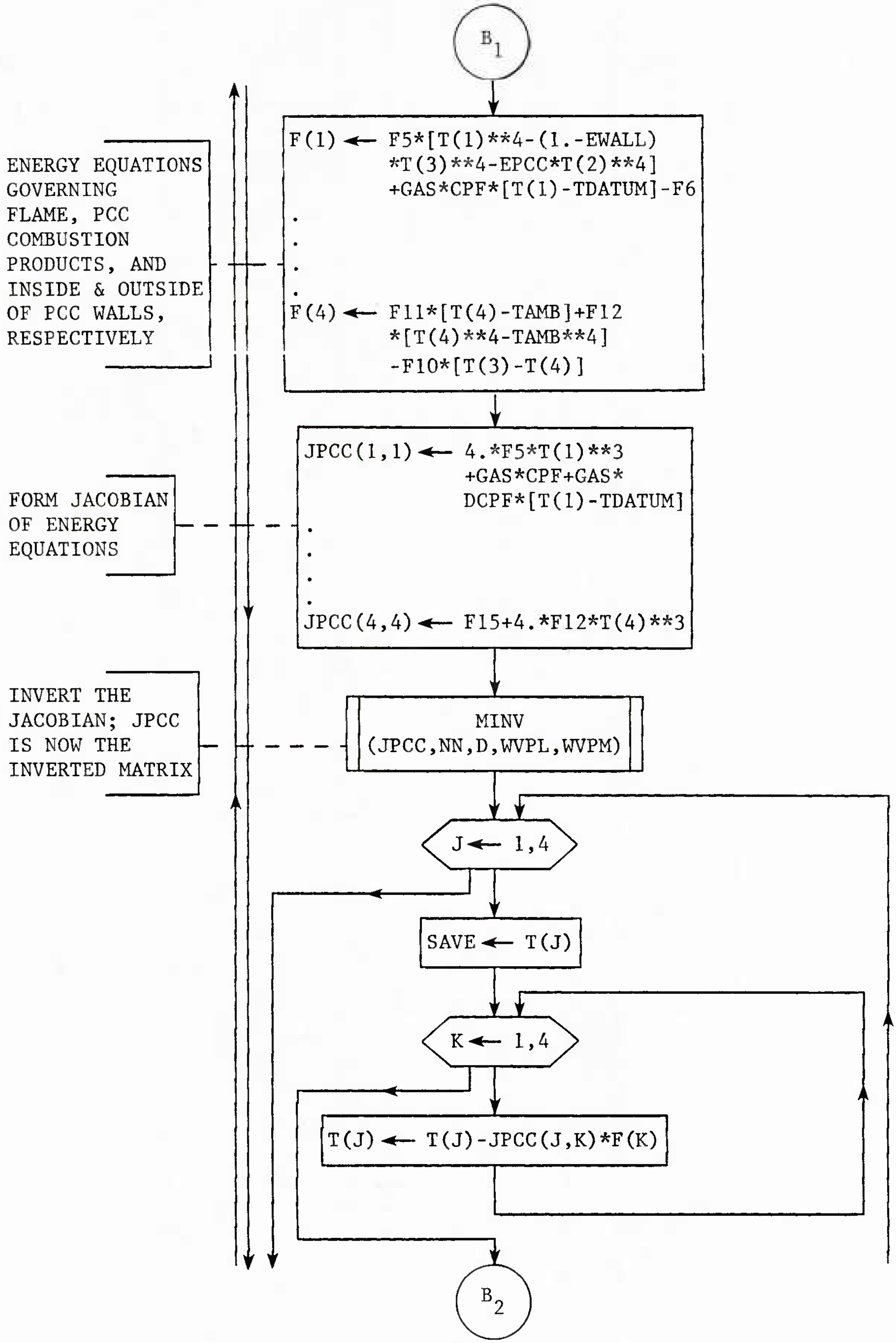

C
SOLVE ENERGY EQUATIONS GOVERNING SECONDARY COMBUSTION CHAMBER
D
SOLVE FOR TEMPERATURES AND STEAM GENERATION
SOLVE ENERGY EQUATIONS GOVERNING GAS FLOWS THROUGH CONVECTION BOILER
E
CALCULATE STEAM GENERATED BY WATERWALLS
CALCULATE EFFICIENCIES
STOP

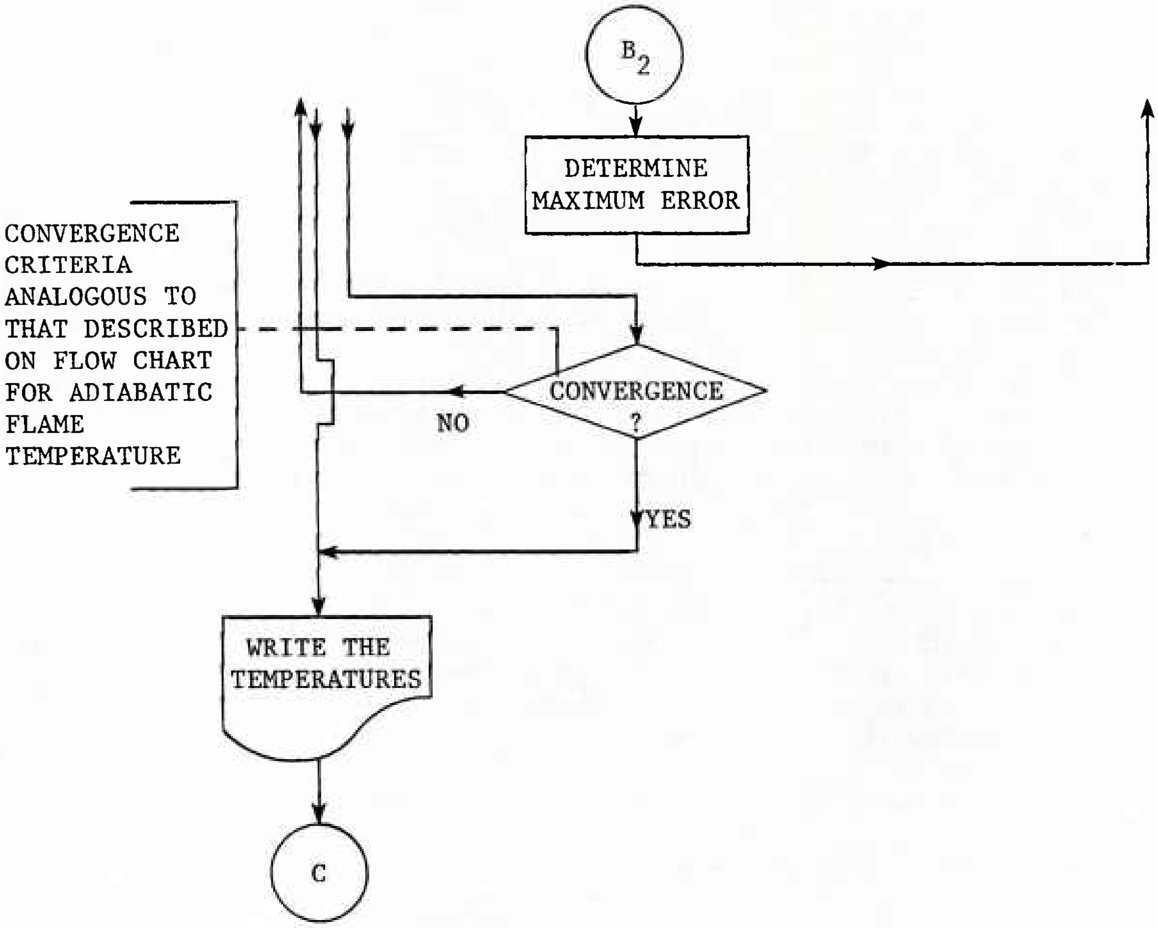

A
CARBON(1) ← CARBON(1)-F1*C(2)/1200.
HYD ← HYD-F1*H(2)/100.
OXY ← OXY-F1*O(2)/1600.
NIT ← [N(1)-F1*N(2)]/1400.
ELEMENTAL C,H,O, AND N REMAINING AFTER SUBTRACTING ASH
O2(1) ← 0.434*AIRPCC/FUEL
N2 ← 3.76*O2(1)+NIT/2.
COMBUSTION AIR
EQUATE
COMPOSITION OF PRODUCTS OF COMBUSTION: H_2O, CO_2, CO
QFLAME ← CO2*HTCO2+H2O(2)*HTH2O(1)+CO*HTCO+HTFUEL
HTLOST ← F4*HFG
HTFLME ← (QFLAME-HTLOST)*FUEL
ENERGY RELEASED TO FLAME
GAS ← FUEL/(1.-WATER/100.)+60.*AIRPCC-ASH
HTOTAL ← H2O(1)+H2O(2)
HTIN ← SPHT(AMBIENT)*GAS*(TAMB-TDATUM)+HTFLME
TFLAME(1) ← 3000.
INITIAL GUESS OF ADIABATIC FLAME TEMPERATURE
DEV ← TFLAME(1)
A_1



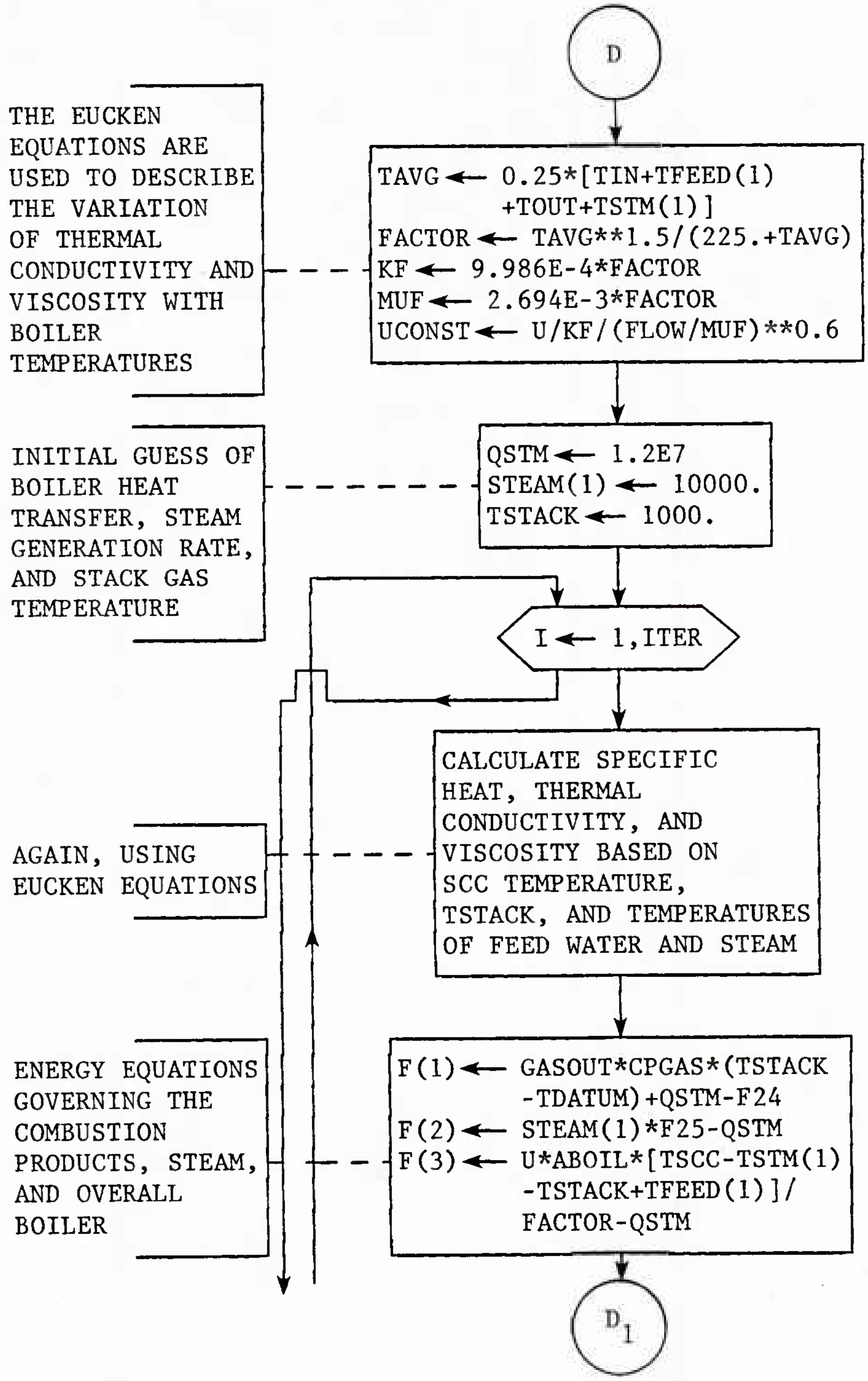
A1
I ← 1,ITER
CPOUT ← SPHT(FLAME)
F(1) ← GAS*CPOUT*[TFLAME(1)-TDATUM]+HTFLME
DFDT ← GAS*CPOUT+GAS*[TFLAME(1)-TDATUM]*DCPDT(FLAME)
TFLAME(1) ← TFLAME(1)-F(1)/DFDT
NEWTON-RAPHSON ITERATION
DEVOLD ← DEV
DEV ← ABS[F(1)/DFDT]
DEV ≤ DEVOLD
YES
NO
CHECK IF ITERATION IS CONVERGING
WRITE "ITERATION IS DIVERGING..."
STOP
IF NOT, TERMINATE RUN
CHECK IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
DEV ≤ TOL
NO
YES
A2
A2

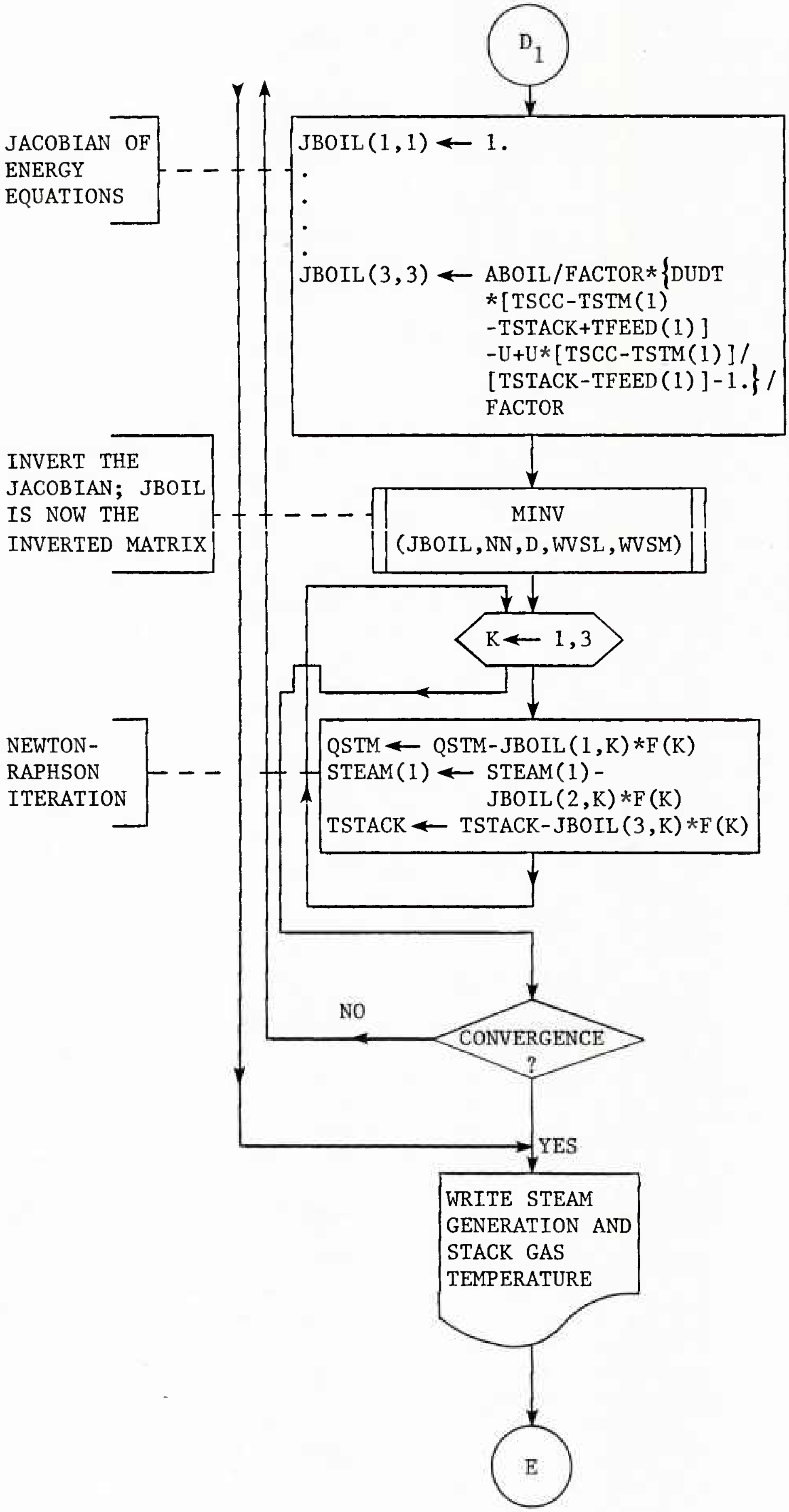

A2
WRITE "ITERATION DID NOT CONVERGE TO WITHIN TOL AFTER ITER ITERATIONS"
A2
WRITE FLAME TEMPERATURE, GAS COMPOSITION, ETC.
B
ADD CONTRIBUTION OF PCC OIL BURNER AND DETERMINE PCC COMBUSTION PRODUCTS AND ENERGY RELEASED IN THE SAME MANNER AS WITH THE ADIABATIC FLAME CALCULATIONS
SIMPLIFY ITERATION BY COMBINING CONSTANTS
F5 ← AFLAME*SIGMA
.
.
.
.
F16 ← F6-F9-HTFLME
INITIAL GUESS OF TEMPERATURE OF FLAME, PCC GASES, AND INSIDE AND OUTSIDE OF PCC WALLS
T(1) ← 3500.
T(2) ← 3200.
T(3) ← 3000.
T(4) ← 1000.
I ← 1,ITER
SPECIFIC HEATS, EMISSIVITIES, AND THEIR DERIVATIVES ARE FUNCTIONS OF UNKNOWN TEMPERATURES AND MUST BE INCLUDED IN THE ITERATION
CPF ← SPHT(FLAME)
CPP ← SPHT(PCC GASES)
DCPF ← DCPDT(FLAME)
DCPP ← DCPDT(PCC GASES)
EFLME ← EMISS(FLAME)
EPCC ← EMISS(PCC GASES)
EWALL ← EMISS(WALL)
DEFLME ← DEDT(FLAME)
DEPCC ← DEDT(PCC GASES)
DEWALL ← DEDT(WALL)
B1


B1
ENERGY EQUATIONS GOVERNING FLAME, PCC COMBUSTION PRODUCTS, AND INSIDE & OUTSIDE OF PCC WALLS, RESPECTIVELY
F(1) ← F5*[T(1)**4-(1.-EWALL) *T(3)**4-EPCC*T(2)**4] +GAS*CPF*[T(1)-TDATUM]-F6
F(4) ← F11*[T(4)-TAMB]+F12 *[T(4)**4-TAMB**4] -F10*[T(3)-T(4)]
FORM JACOBIAN OF ENERGY EQUATIONS
JPCC(1,1) ← 4.*F5*T(1)**3 +GAS*CPF+GAS* DCPF*[T(1)-TDATUM]
JPCC(4,4) ← F15+4.*F12*T(4)**3
INVERT THE JACOBIAN; JPCC IS NOW THE INVERTED MATRIX
MINV (JPCC,NN,D,WVPL,WVPM)
J ← 1,4
SAVE ← T(J)
K ← 1,4
T(J) ← T(J)-JPCC(J,K)*F(K)
B2

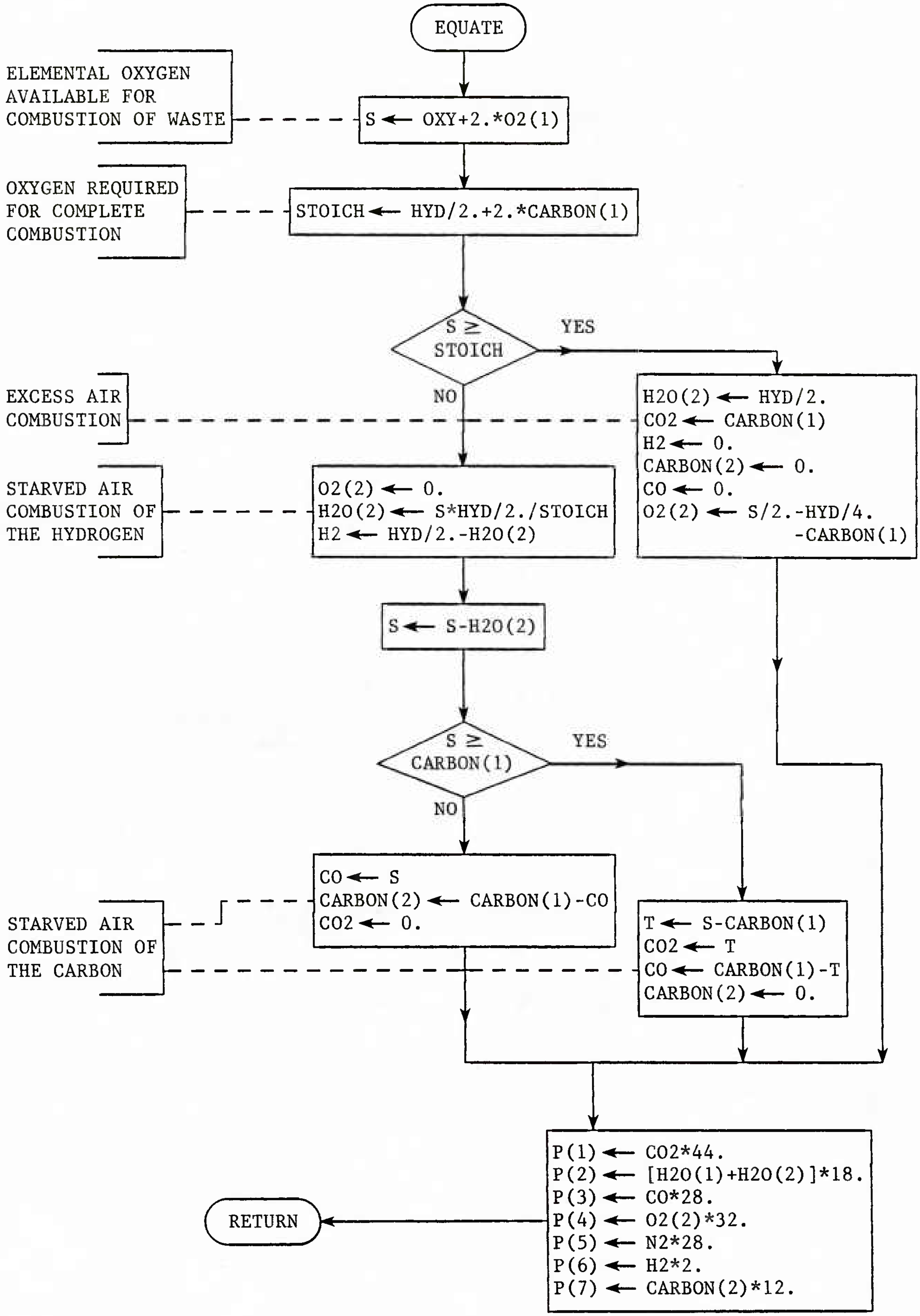


B_2
DETERMINE MAXIMUM ERROR
CONVERGENCE CRITERIA ANALOGOUS TO THAT DESCRIBED ON FLOW CHART FOR ADIABATIC FLAME TEMPERATURE
CONVERGENCE ?
NO
YES
WRITE THE TEMPERATURES
C

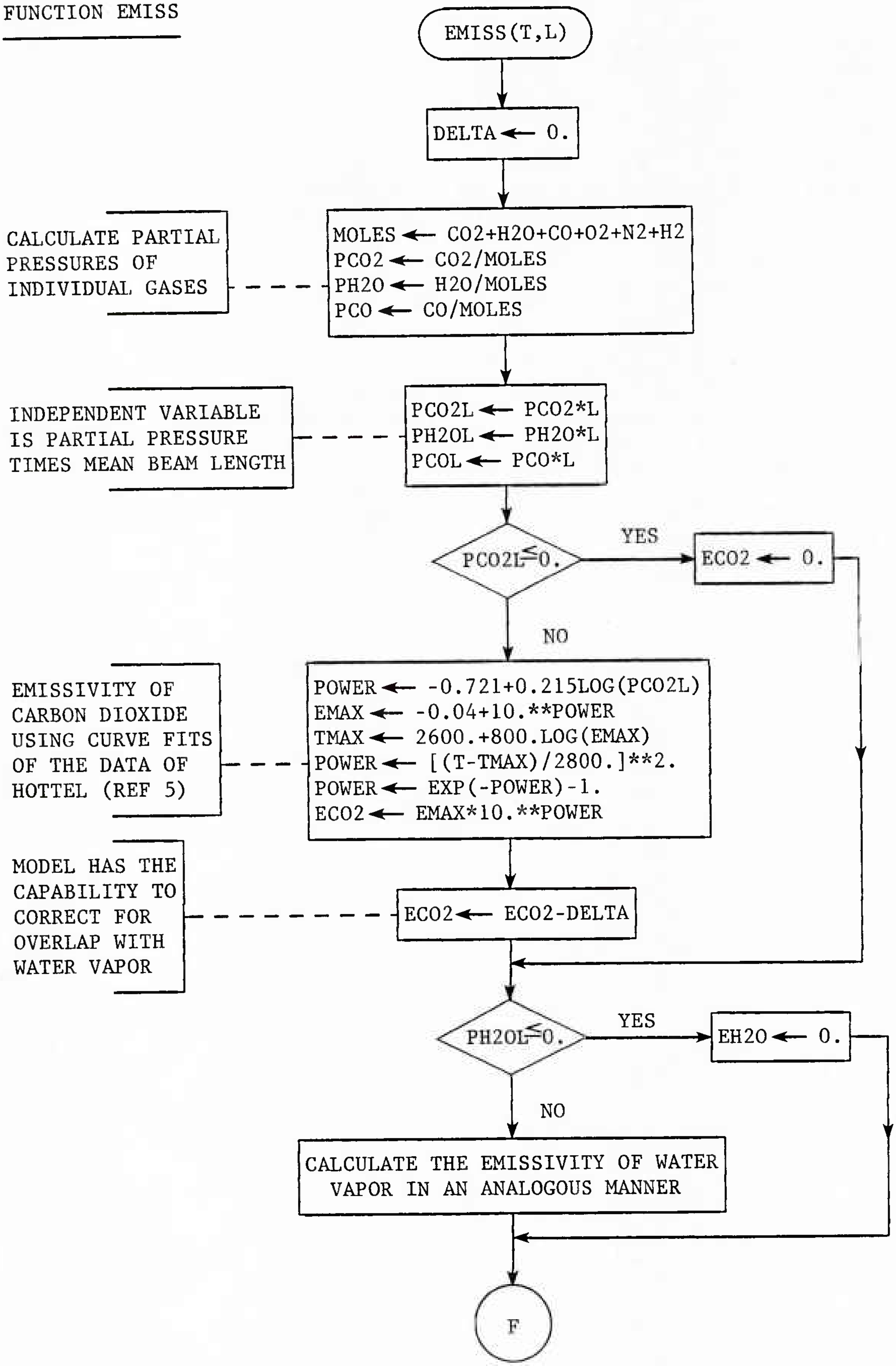

D
THE EUCKEN EQUATIONS ARE USED TO DESCRIBE THE VARIATION OF THERMAL CONDUCTIVITY AND VISCOSITY WITH BOILER TEMPERATURES
TAVG ← 0.25*[TIN+TFEED(1) +TOUT+TSTM(1)]
FACTOR ← TAVG**1.5/(225.+TAVG)
KF ← 9.986E-4*FACTOR
MUF ← 2.694E-3*FACTOR
UCONST ← U/KF/(FLOW/MUF)**0.6
INITIAL GUESS OF BOILER HEAT TRANSFER, STEAM GENERATION RATE, AND STACK GAS TEMPERATURE
QSTM ← 1.2E7
STEAM(1) ← 10000.
TSTACK ← 1000.
I ← 1,ITER
AGAIN, USING EUCKEN EQUATIONS
CALCULATE SPECIFIC HEAT, THERMAL CONDUCTIVITY, AND VISCOSITY BASED ON SCC TEMPERATURE, TSTACK, AND TEMPERATURES OF FEED WATER AND STEAM
ENERGY EQUATIONS GOVERNING THE COMBUSTION PRODUCTS, STEAM, AND OVERALL BOILER
F(1) ← GASOUT*CPGAS*(TSTACK -TDATUM)+QSTM-F24
F(2) ← STEAM(1)*F25-QSTM
F(3) ← U*ABOIL*[TSCC-TSTM(1) -TSTACK+TFEED(1)]/ FACTOR-QSTM
D1

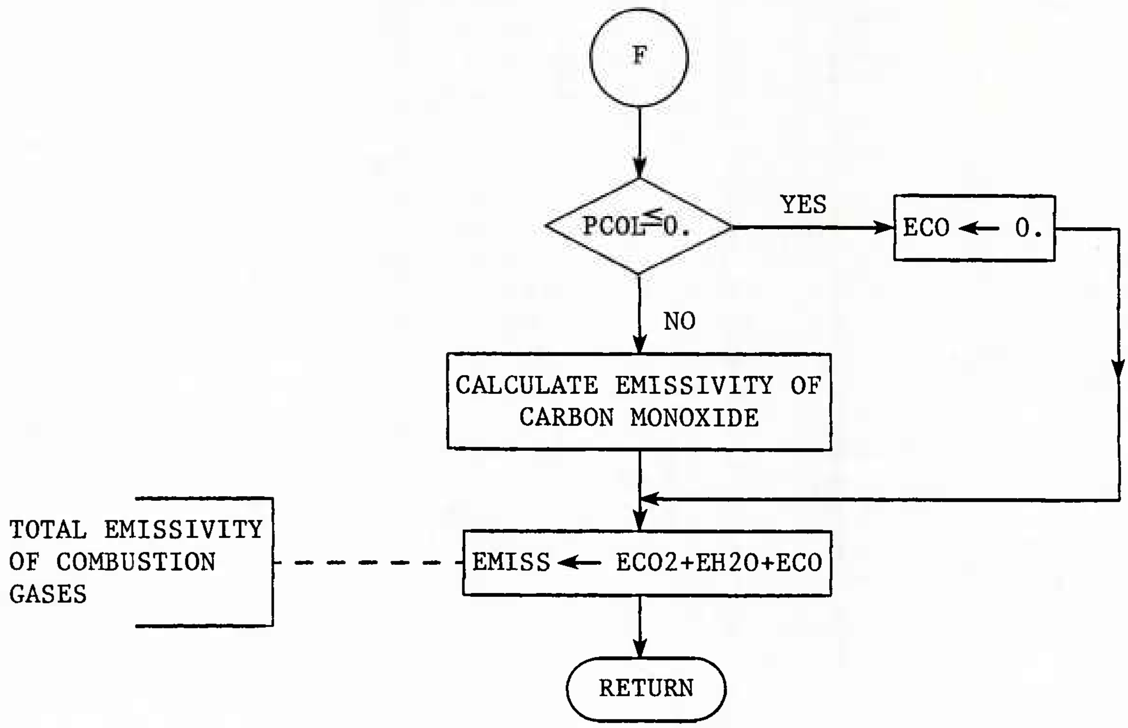

D1
JACOBIAN OF ENERGY EQUATIONS
JBOIL(1,1) ← 1.
.
.
.
.
JBOIL(3,3) ← ABOIL/FACTOR*{DUDT *[TSCC-TSTM(1) -TSTACK+TFEED(1)] -U+U*[TSCC-TSTM(1)]/ [TSTACK-TFEED(1)]-1.}/ FACTOR
INVERT THE JACOBIAN; JBOIL IS NOW THE INVERTED MATRIX
MINV (JBOIL,NN,D,WVSL,WVSM)
K ← 1,3
NEWTON-RAPHSON ITERATION
QSTM ← QSTM-JBOIL(1,K)*F(K)
STEAM(1) ← STEAM(1)- JBOIL(2,K)*F(K)
TSTACK ← TSTACK-JBOIL(3,K)*F(K)
NO
CONVERGENCE ?
YES
WRITE STEAM GENERATION AND STACK GAS TEMPERATURE
E

SUBROUTINE EQUATE



FUNCTION EMISS




F
PCOL ≤ 0.
YES
ECO ← 0.
NO
CALCULATE EMISSIVITY OF CARBON MONOXIDE
TOTAL EMISSIVITY OF COMBUSTION GASES
EMISS ← ECO2+EH2O+ECO
RETURN

FORTRAN Listing

```
      PROGRAM HRI (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C  PROGRAM TO PREDICT THE PERFORMANCE OF INCINERATORS BURNING SOLID
C  WASTE AND USING A BOILER TO RECOVER THE HEAT....IT IS ASSUMED THAT
C  EQUILIBRIUM EXISTS, THAT THE CHEMICAL REACTIONS GO TO COMPLETION,
C  AND THAT THE REACTION RATES ARE LIMITED ONLY BY THE FUEL AND AIR
C  SUPPLIES....INTERMEDIATE HYDROCARBONS ARE NEGLECTED, THE REACTION
C  PRODUCTS CONSIST OF H2O, CO2, CO, O2, N2, H2, AND C
C  PROGRAM DEVELOPED BY CA KODRES OF THE NAVAL CIVIL ENGINEERING LAB,
C  PORT HUENEME, CALIFORNIA 93043
C  DATE OF THIS VERSION: 07 AUG 1984
      REAL KW,KWALL(2),LEAK(3),N(3),NIT,N2,LPCC,LSCC
      REAL JPCC(4,4),JSCC(3,3),JBOIL(3,3),N2F,KF,MUF
      REAL LOSSES(10),INPUT(5)
      INTEGER TYPE
      COMMON/GASES/CO2,H2O(2),CO,O2(2),N2,H2
      COMMON/ELEMENT/HYD,NIT,OXY,CARBON(2),P(7)
      DIMENSION AIROIL(2),C(3),X(3),H(3),HCONV(3),O(3),HTH2O(2),
     1HHV(3),OIL(2),TFLAME(2),TSHELL(2),TWALL(2),RATIO(16)
      DIMENSION F(4),T(4),WVPL(4),WVPM(4),WVSL(3),WVSM(3)
      DIMENSION TSTM(3),PSTM(3),HSTM(3),HFEED(3),TFEED(3),STEAM(3)
     1,BD(3)
      DATA ITER,TOL/100,1./
      DATA TDATUM,HTCO2,HTCO,HTH2O(1),HTH2O(2),SIGMA/ 520.,169182.,
     147517.,103968.,122890.,0.1714E-8/
      DATA HFG,HDATUM/970.3,28.06/
C
C  INPUT THE MASS FLOW RATE OF THE FUEL (WET WASTE) IN LB/HR AND ITS
C  HIGHER HEATING VALUE (DRY) IN BTU/LB
      READ(5,1) FUEL,HHV(1)
C  INPUT THE ULTIMATE ANALYSIS OF THE FUEL, PERCENT BY DRY WEIGHT,
C  CARBON, HYDROGEN, OXYGEN, NITROGEN, AND EVERYTHING ELSE COMBINED
      READ(5,2) C(1),H(1),O(1),N(1),X(1)
C  INPUT THE PROXIMATE ANALYSIS OF THE FUEL, PERCENT BY WEIGHT,
C  MOISTURE, VOLATILE MATTER, FIXED CARBON, AND ASH
      READ(5,3) WATER, VM, FC, ASHE
C  INPUT THE MASS FLOW RATE OF THE ASH IN LB/HR AND ITS HIGHER HEATING
C  VALUE IN BTU/LB
      READ(5,1) ASH,HHV(2)
C  INPUT THE ULTIMATE ANALYSIS OF THE ASH
      READ(5,2) C(2),H(2),O(2),N(2),X(2)
C  INPUT THE MASS FLOW RATE OF OIL SUPPLIED TO BURNERS IN LB/HR, THE
C  PRIMARY AND SECONDARY BURNERS IN THAT ORDER, AND THE HIGHER HEATING
C  VALUE OF THE OIL IN BTU/LB
      READ(5,4) OIL(1),OIL(2),HHV(3)
C  INPUT THE ULTIMATE ANALYSIS OF THE OIL....IF THERE IS NO OIL SUPPLIED
C  TO EITHER BURNER THEN INPUT ZEROES
      READ(5,2) C(3),H(3),O(3),N(3),X(3)
C  INPUT ALL OTHER POWER REQUIREMENTS IN KILOWATTS....THIS IS A COMBINED
C  VALUE, INCLUDING ALL BLOWERS, PUMPS, WASTE PROCESSING EQUIPMENT, ETC.
      READ(5,5) KW
```

```
C  INPUT THE COMBUSTION AIR IN LB/MIN....UNDERFIRE AIR, OVERFIRE AIR,
C  AIR TO SECONDARY COMBUSTION CHAMBER AND TO THE PRIMARY AND SECONDARY
C  OIL BURNERS, IN THAT ORDER....AIR TO THE OIL BURNERS AND PCC LEAKAGE
C  AIR IS CONSIDERED TO BE OVERFIRE
      READ(5,2) AIRPCC,AIROF,AIRSCC,AIROIL(1),AIROIL(2)
C  INPUT LEAKAGE AIR TO THE PCC, SCC, AND DOWN THE DUMP STACK IN LB/MIN
C  USE MINUS(-) SIGN FOR LEAKAGE OUT OF THE INCINERATOR
      READ(5,4) (LEAK(I),I=1,3)
C  INPUT THE HEAT TRANSFER PARAMETERS....THE SURFACE AREAS OF THE FLAME
C  FRONT, PRIMARY AND SECONDARY COMBUSTION CHAMBERS IN SQFT, CONVECTION
C  FILM COEFFICIENTS TO INNER WALLS OF PCC AND SCC AND TO OUTER SURFACE
C  OF INCINERATOR IN BTU/HR-SQFT-DEGF, EFFECTIVE THERMAL CONDUCTANCE
C  THRU WALLS OF PCC AND SCC IN BTU/HR-SQFT-DEGF
      READ(5,6) AFLAME,APCC,ASCC,(HCONV(I),I=1,3),KWALL(1),KWALL(2)
C  INPUT THE AMBIENT AIR TEMPERATURE IN DEGF, THE EMISSIVITY OF THE
C  OUTER SHELL OF THE INCINERATOR, AND THE MEAN BEAM LENGTH OF THE
C  PRIMARY AND SECONDARY COMBUSTION CHAMBERS IN FEET
      READ(5,3) TAMB,ESHELL,LPCC,LSCC
C  INPUT CODE TO DESIGNATE TYPE OF HRI CONFIGURATION
C       "1" SIGNIFIES NO BOILERS
C       "2" SIGNIFIES CONVECTION BOILER AT SCC EXIT
C       "3" SIGNIFIES PCC WATER-WALL BOILER
C       "4" SIGNIFIES SCC WATER-WALL BOILER
C       "5" SIGNIFIES BOTH PCC WATER-WALLS AND CONVECTION BOILER
C       "6" SIGNIFIES BOTH SCC WATER-WALLS AND CONVECTION BOILER
C       "7" SIGNIFIES BOTH PCC AND SCC WATER-WALLS
C       "8" SIGNIFIES ALL THREE BOILERS SIMULTANEOUSLY
      READ(5,93) TYPE
      IF (TYPE.EQ.1) GO TO 12
      IF ((TYPE.EQ.3).OR.(TYPE.EQ.4).OR.(TYPE.EQ.7)) GO TO 7
C  INPUT CONVECTION BOILER CHARACTERISTICS....SURFACE AREA OF TUBES IN
C  SQFT, THE FEED WATER TEMPERATURE IN DEGF, THE FEED WATER ENTHALPY IN
C  BTU/LB, THE TEMP AND ENTHALPY OF THE STEAM, THE ENTHALPY OF THE
C  SATURATED LIQUID, AND THE STEAM PRESSURE IN PSIA,  INPUT THE BLOWDOWN
C  IN FRACTION OF STEAM GENERATED
C  OTHER LOSSES FROM THE BOILER SUCH AS LEAKAGE AND HEAT TRANSFER TO
C  THE ENVIRONMENT MAY BE LUMPED IN WITH THE BLOWDOWN
      READ(5,6) ABOIL,TFEED(1),HFEED(1),TSTM(1),HSTM(1),HEVAP,PSTM(1)
     1,BD(1)
      BD(1)=100.*BD(1)
C  INPUT CONVECTION BOILER DESIGN POINT....THE OVERALL H.T. COEFFICIENT
C  IN BTU/HR-SQFT-DEGF, THE COMBUSTION GAS TEMPS ENTERING AND LEAVING
C  THE BOILER IN DEGF, AND THE FLOW RATE OF COMBUSTION GASES IN LB/HR
      READ(5,3) U,TIN,TOUT,FLOW
      IF (TYPE.EQ.2) GO TO 12
    7 IF ((TYPE.EQ.4).OR.(TYPE.EQ.6)) GO TO 8
C  INPUT CHARACTERISTICS OF PCC WATER-WALL BOILER....STEAM TEMPERATURE,
C  PRESSURE, AND ENTHALPY....TEMPERATURE AND ENTHALPY OF FEED WATER
C  AND "BLOWDOWN" LOSSES, ETC
      READ(5,6) TSTM(2),PSTM(2),HSTM(2),TFEED(2),HFEED(2),BD(2)
      BD(2)=BD(2)*100.
      IF ((TYPE.EQ.3).OR.(TYPE.EQ.5)) GO TO 12
```

```
C   INPUT CHARACTERISTICS OF SCC WATER-WALL BOILER....STEAM TEMPERATURE,
C   PRESSURE, AND ENTHALPY....TEMPERATURE AND ENTHALPY OF FEED WATER
C   AND "BLOWDOWN" LOSSES, ETC
  8 READ(5,6) TSTM(3),PSTM(3),HSTM(3),TFEED(3),HFEED(3),BD(3)
    BD(3)=BD(3)*100.
C
C   PRINT ALL INPUT AND BOUNDARY CONDITIONS
 12 WRITE(6,73)
    WRITE(6,9) FUEL,HHV(1)
    WRITE(6,10) C(1),WATER,H(1),VM,O(1),FC,N(1),ASHE,X(1)
    WRITE(6,11) ASH,HHV(2)
    WRITE(6,74)
    WRITE(6,13) C(2),H(2),O(2),N(2),X(2)
    WRITE(6,14) OIL(1),OIL(2),HHV(3)
    WRITE(6,15)
    WRITE(6,13) C(3),H(3),O(3),N(3),X(3)
    WRITE(6,16) AIRPCC,AIROF,AIRSCC,AIROIL(1),AIROIL(2)
    WRITE(6,17) (LEAK(I),I=1,3)
    WRITE(6,18) TAMB
    WRITE(6,19) AFLAME,APCC,ASCC
    WRITE(6,34) ESHELL
    WRITE(6,36) (HCONV(I),I=1,3),KWALL(1),KWALL(2),LPCC,LSCC
    IF (TYPE.EQ.1) WRITE(6,76)
    IF (TYPE.EQ.2) WRITE(6,77)
    IF (TYPE.EQ.3) WRITE(6,78)
    IF (TYPE.EQ.4) WRITE(6,79)
    IF (TYPE.EQ.5) WRITE(6,81)
    IF (TYPE.EQ.6) WRITE(6,82)
    IF (TYPE.EQ.7) WRITE(6,83)
    IF (TYPE.EQ.8) WRITE(6,84)
    IF (TYPE.EQ.1) GO TO 109
    IF ((TYPE.EQ.3).OR.(TYPE.EQ.4).OR.(TYPE.EQ.7)) GO TO 101
    WRITE(6,20) ABOIL,TFEED(1),HFEED(1),TSTM(1),PSTM(1),HSTM(1)
   1,HEVAP,BD(1)
    WRITE(6,21) U
    TFEED(1)=TFEED(1)+460.
    TSTM(1)=TSTM(1)+460.
    TIN=TIN+460.
    TOUT=TOUT+460.
    BD(1)=BD(1)/100.
    IF (TYPE.EQ.2) GO TO 109
101 IF ((TYPE.EQ.4).OR.(TYPE.EQ.6)) GO TO 106
    WRITE(6,86) APCC,TFEED(2),HFEED(2),TSTM(2),PSTM(2),HSTM(2)
   1,BD(2)
    TSTM(2)=TSTM(2)+460.
    BD(2)=BD(2)/100.
    IF ((TYPE.EQ.3).OR.(TYPE.EQ.5)) GO TO 109
106 WRITE(6,87) ASCC,TFEED(3),HFEED(3),TSTM(3),PSTM(3),HSTM(3)
   1,BD(3)
    TSTM(3)=TSTM(3)+460.
    BD(3)=BD(3)/100.
C
```

```
C  DETERMINE MASS FLOW RATE OF DRY FUEL
  109 FUEL=FUEL*(1.-WATER/100.)
C
C  PRELIMINARY AND SIMPLIFYING CALCULATIONS
      TAMB=TAMB+460.
      LEAK(1)=LEAK(1)+AIROF
      INPUT(4)=0.
      OUTPUT=0.
      LOSSES(9)=0.
      F1=ASH/FUEL
      F2=OIL(1)/FUEL
      F3=OIL(2)/FUEL
      F4=WATER/(100.-WATER)
C
C  CALCULATE STOICHIOMETRIC AIR BY BALANCING EQUATION OF COMBUSTION....
C  NOTE THAT THE FUEL HAS A MOLECULAR WEIGHT OF ONE
      CARBON(1)=C(1)/1200.
      HYD=H(1)/100.
      OXY=O(1)/1600
      CO2=CARBON(1)
      H2O(1)=F4/18.
      H2O(2)=HYD/2.
      O2(1)=(2.*CO2+H2O(2)-OXY)/2.
      STOICH=(32.+3.76*28.)*O2(1)*FUEL/60.
C  CALCULATE THE HEAT ABSORBED IN BREAKING DOWN THE FUEL
      HTFUEL=HHV(1)-H2O(2)*HTH2O(2)-CO2*HTCO2
      P(1)=CO2*44.
      P(2)=(H2O(1)+H2O(2))*18.
      DO 25 I=3,7
      P(I)=0.
   25 CONTINUE
      P(5)=105.28*O2(1)+N(1)/100.
      WRITE(6,22) STOICH,HTFUEL
      IF (TYPE.EQ.8) WRITE(6,103)
      WRITE(6,23)
      WRITE(6,24) (P(I),I=1,7)
C
C  CALCULATE THE ADIABATIC FLAME TEMPERATURE, FIRST DEDUCT FUEL NOT
C  BURNED, IE LEAVING THE INCINERATOR AS ASH....THE SENSIBLE ENERGY OF
C  THE ASH IS NEGLECTED
      CARBON(1)=CARBON(1)-F1*C(2)/1200.
      HYD=HYD-F1*H(2)/100.
      OXY=OXY-F1*O(2)/1600.
      NIT=(N(1)-F1*N(2))/1400.
      O2(1)=0.434*AIRPCC/FUEL
      N2=3.76*O2(1)+NIT/2.
      CALL EQUATE
C  THEN CALCULATE HEAT RELEASED TO FLAME IN BTU/LB OF FUEL
      QFLAME=CO2*HTCO2+H2O(2)*HTH2O(1)+CO*HTCO+HTFUEL
C  HEAT LOST VAPORIZING THE MOISTURE PRESENT IN THE FUEL
      HTLOST=F4*HFG
      HTFLME=(QFLAME-HTLOST)*FUEL
```

```
C  TOTAL MASS FLOW THRU THE FLAME IN LBS/HR
      GAS=FUEL/(1.-WATER/100.)+60.*AIRPCC-ASH
C  THE ADIABATIC FLAME TEMPERATURE CAN NOW BE DETERMINED BY CONDUCTING
C  AN ENERGY BALANCE ON THE BURNING FUEL....THE SPECIFIC HEAT VARIES
C  WITH TEMPERATURE, MAKING THE RESULTING EQUATION NON-LINEAR
C  IT IS SOLVED BY EMPLOYING A NEWTON-RAPHSON ITERATION
      HTOTAL=H2O(1)+H2O(2)
      HTIN=SPHT(TAMB,O2(2),N2,CO,H2,HTOTAL,CO2)*GAS*(TAMB-TDATUM)+HTFLME
      TFLAME(1)=3000.
      DEV=TFLAME(1)
      DO 40 I=1,ITER
      CPOUT=SPHT(TFLAME(1),O2(2),N2,CO,H2,HTOTAL,CO2)
      F(1)=GAS*CPOUT*(TFLAME(1)-TDATUM)-HTIN
      DFDT=GAS*CPOUT+GAS*(TFLAME(1)-TDATUM)*DCPDT(TFLAME(1),O2(2),N2,
     1CO,H2,HTOTAL,CO2)
      DEVOLD=DEV
      TFLAME(1)=TFLAME(1)-F(1)/DFDT
C  CHECK TO SEE IF ITERATION IS CONVERGING
      DEV=ABS(F(1)/DFDT)
      IF (DEV.LE.DEVOLD) GO TO 35
      WRITE(6,26)
      WRITE(6,27)
      WRITE(6,28)
      GO TO 200
C  CHECK TO SEE IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
   35 IF (DEV.LE.TOL) GO TO 45
   40 CONTINUE
      WRITE(6,26)
      WRITE(6,29) TOL,ITER
      WRITE(6,28)
   45 CONTINUE
      FLAME=TFLAME(1)-460.
      IF ((TYPE.EQ.5).OR.(TYPE.EQ.6).OR.(TYPE.EQ.7)) WRITE(6,103)
      WRITE(6,30) FUEL,QFLAME,HTLOST,GAS,FLAME
      WRITE(6,31)
      WRITE(6,24) (P(I),I=1,7)
C
C  STORE THE FLAME COMPOSITION FOR USE IN CALCULATING ACTUAL TEMPS
      O2F=O2(2)
      N2F=N2
      COF=CO
      H2F=H2
      HTOTF=HTOTAL
      CO2F=CO2
C  ADD CONTRIBUTION FROM PRIMARY OIL BURNER....FIRST CALC HEAT ABSORBED
C  IN BREAKING DOWN OIL, THEN GET OVERALL COMPOSITION OF GASES IN PCC
      COIL=C(3)/1200.
      HOIL=H(3)/100.
      HTOIL=HHV(3)-HOIL/2.*HTH2O(2)-COIL*HTCO2
      HTOILP=HTOIL*F2
      CARBON(1)=CARBON(1)+F2*COIL
      HYD=HYD+F2*HOIL
      OXY=OXY+F2*O(3)/1600.
      NIT=NIT+F2*N(3)/1400.
```

```
C  INCLUDE BOTH PRIMARY OIL AIR AND PCC LEAKAGE WITH PCC COMBUSTION AIR
      O2(1)=0.434/FUEL*(AIRPCC+AIROIL(1)+LEAK(1))
      N2=3.76*O2(1)+NIT/2.
      CALL EQUATE
C  TOTAL HEAT RELEASED DURING COMBUSTION OF WASTE AND PCC OIL
      HTCOMB=CO2*HTCO2+H2O(2)*HTH2O(1)+CO*HTCO+HTFUEL+HTOILP-HTLOST
C  HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER
      HTCOMB=HTCOMB-HTFLME/FUEL
      HTPCC=HTCOMB*FUEL
      GASPCC=GAS+OIL(1)+(AIROIL(1)+LEAK(1))*60.
C
C  SOLVE ENERGY EQUATIONS GOVERNING FLAME FRONT, PRIMARY COMBUSTION
C  CHAMBER INTERIOR, AND THE WALLS OF THE PCC SIMULTANEOUSLY..USING
C  NEWTONS METHOD..TO DETERMINE ACTUAL INCINERATOR TEMPERATURES
C
C  NOTE THAT THE INTERIOR OF BOTH COMBUSTION CHAMBERS IS CONSIDERED
C  TO BE HOMOGENEOUS AND THE COMBUSTION PRODUCTS ACT AS PERFECT GASES
C
C  SIMPLIFY ITERATION BY COMBINING CONSTANTS WHERE POSSIBLE
      F5=AFLAME*SIGMA
      F6=GAS*SPHT(TAMB,O2F,N2F,COF,H2F,HTOTF,CO2F)*(TAMB-TDATUM)+HTFLME
      F7=HCONV(1)*APCC
      F8=APCC*SIGMA
      HTOTAL=H2O(1)+H2O(2)
      F9=GASPCC*SPHT(TAMB,O2(2),N2,CO,H2,HTOTAL,CO2)*(TAMB-TDATUM)+HTPCC
      F10=KWALL(1)*APCC
      F11=HCONV(3)*APCC
      F12=APCC*SIGMA*ESHELL
      F13=(AFLAME+APCC)*SIGMA
      F14=APCC*(KWALL(1)+HCONV(1))
      F15=APCC*(KWALL(1)+HCONV(3))
      F16=F6-F9-HTFLME
C  INITIALIZE TEMPERATURES AND ITERATION PARAMETERS
      T(1)=3500.
      T(2)=3200.
      T(3)=3000.
      T(4)=1000.
      IF ((TYPE.EQ.1).OR.(TYPE.EQ.2).OR.(TYPE.EQ.4).OR.(TYPE.EQ.6))
     1GO TO 121
      T(3)=TSTM(2)
      T(4)=600.
  121 NN=4
      D=0.
      DEVMAX=T(1)
C
```

```
C   BEGIN THE ITERATION
      DO 65 I=1,ITER
      DSAVE=DEVMAX
      DEVMAX=0.
      CPF=SPHT(T(1),O2F,N2F,COF,H2F,HTOTF,CO2F)
      CPP=SPHT(T(2),O2(2),N2,CO,H2,HTOTAL,CO2)
      DCPF=DCPDT(T(1),O2F,N2F,COF,H2F,HTOTF,CO2F)
      DCPP=DCPDT(T(2),O2(2),N2,CO,H2,HTOTAL,CO2)
      EFLME=EMISS(T(1),LPCC)
      EPCC=EMISS(T(2),LPCC)
      EWALL=EMISS(T(3),LPCC)
      DEFLME=DEDT(T(1),LPCC)
      DEPCC=DEDT(T(2),LPCC)
      DEWALL=DEDT(T(3),LPCC)
C   UPDATE THE FUNCTIONS
      F(1)=F5*(T(1)**4-(1.-EWALL)*T(3)**4-EPCC*T(2)**4)+GAS*CPF*
     1(T(1)-TDATUM)-F6
      F(2)=GASPCC*CPP*(T(2)-TDATUM)+F8*(EPCC*T(2)**4-EWALL*T(3)**4)+
     1F7*(T(2)-T(3))-F5*(EFLME*T(1)**4-EPCC*T(2)**4)-GAS*CPF*(T(1)-
     2TDATUM)+F16
      F(3)=F10*(T(3)-T(4))-F8*(EPCC*T(2)**4-EWALL*T(3)**4)-F5*((1.-
     1EFLME)*T(1)**4-(1.-EWALL)*T(3)**4)-F7*(T(2)-T(3))
      F(4)=F11*(T(4)-TAMB)+F12*(T(4)**4-TAMB**4)-F10*(T(3)-T(4))
C   CALCULATE THE JACOBIAN OF THE ENERGY EQUATIONS
      JPCC(1,1)=4.*F5*T(1)**3+GAS*CPF+GAS*DCPF*(T(1)-TDATUM)
      JPCC(1,2)=-F5*T(2)**3*(4.*EPCC+T(2)*DEPCC)
      JPCC(1,3)=F5*T(3)**3*(T(3)*DEWALL-4.*(1.-EWALL))
      JPCC(1,4)=0.
      JPCC(2,1)=-F5*T(1)**3*(4.*EFLME+T(1)*DEFLME)-GAS*(CPF+DCPF*
     1(T(1)-TDATUM))
      JPCC(2,2)=GASPCC*(CPP+DCPP*(T(2)-TDATUM))+F7+F13*T(2)**3*(4.*EPCC
     1+DEPCC*T(2))
      JPCC(2,3)=-F8*T(3)**3*(4.*EWALL+T(3)*DEWALL)-F7
      JPCC(2,4)=0.
      JPCC(3,1)=F5*T(1)**3*(T(1)*DEFLME-4.*(1.-EFLME))
      JPCC(3,2)=-F8*T(2)**3*(4.*EPCC+T(2)*DEPCC)-F7
      JPCC(3,3)=F14+F8*T(3)**3*(4.*EWALL+T(3)*DEWALL)+F5*T(3)**3
     1*(4.*(1.-EWALL)-T(3)*DEWALL)
      JPCC(3,4)=-F10
      JPCC(4,1)=0.
      JPCC(4,2)=0.
      JPCC(4,3)=-F10
      JPCC(4,4)=F15+4.*F12*T(4)**3
      IF ((TYPE.EQ.1).OR.(TYPE.EQ.2).OR.(TYPE.EQ.4).OR.(TYPE.EQ.6))
     1GO TO 111
      F(3)=T(3)-TSTM(2)
      JPCC(3,1)=0.
      JPCC(3,2)=0.
      JPCC(3,3)=1.
      JPCC(3,4)=0.
```

```
C  INVERT THE JACOBIAN
  111 CALL MINV(JPCC,NN,D,WVPL,WVPM)
C  AND THEN IMPROVE ON THE TEMPERATURES
      DO 55 J=1,4
      SAVE=T(J)
      DO 50 K=1,4
      T(J)=T(J)-JPCC(J,K)*F(K)
   50 CONTINUE
      DEV=ABS(T(J)-SAVE)
      IF (DEV.GT.DEVMAX) DEVMAX=DEV
   55 CONTINUE
C  CHECK TO SEE IF ITERATION IS CONVERGING
      IF (DEVMAX.LE.DSAVE) GO TO 60
      WRITE(6,26)
      WRITE(6,37)
      WRITE(6,28)
      GO TO 200
C  CHECK TO SEE IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
   60 IF (DEVMAX.LE.TOL) GO TO 70
   65 CONTINUE
      WRITE(6,26)
      WRITE(6,38) TOL,ITER
      WRITE(6,28)
   70 CONTINUE
      TFLAME(2)=T(1)-460.
      TPCC=T(2)
      TGAS=T(2)-460.
      TWALL(1)=T(3)-460.
      TSHELL(1)=T(4)-460.
      WRITE(6,39) TFLAME(2)
      TFLAME(2)=TFLAME(2)+460.
      WRITE(6,32) HTCOMB,GASPCC
      WRITE(6,41) TGAS,TWALL(1),TSHELL(1)
      IF (TYPE.EQ.1) WRITE(6,103)
      WRITE(6,48) CPP,EPCC
      WRITE(6,33)
      WRITE(6,24) (P(I),I=1,7)
C
C  DETERMINE HEAT TRANSFER LOSS OUT THRU COMB CHAMBER WALLS
      LOSSES(5)=KWALL(1)*APCC*(TWALL(1)-TSHELL(1))
      IF ((TYPE.EQ.1).OR.(TYPE.EQ.2).OR.(TYPE.EQ.4).OR.(TYPE.EQ.6))
     1GO TO 112
C  CALCULATE HEAT TRANSFERRED TO BOILER FOR USE IN LATER STEAM CALCS
C  CONVECTION H.T. FROM COMBUSTION PRODUCTS TO WATER-WALLS
      QCONV=F7*(T(2)-T(3))
C  RADIATION FROM FLAME TO WATER-WALLS
      QRAD1=F5*((1.-EFLME)*T(1)**4-(1.-EWALL)*T(3)**4)
C  RADIATION FROM COMBUSTION PRODUCTS TO PCC WATER-WALLS
      QRAD2=F8*(EPCC*T(2)**4-EWALL*T(3)**4)
C  HEAT CONDUCTED TO OUTER SKIN
      QCOND=F10*(T(3)-T(4))
```

```
C  STORE THE PCC GAS COMPOSITION TO USE AS SCC BOUNDARY CONDITION
 112 O2F=O2(2)
     N2F=N2
     COF=CO
     H2F=H2
     HTOTF=HTOTAL
     CO2F=CO2
C  ADD CONTRIBUTION FROM SECONDARY OIL BURNER
     HTOILS=HTOIL*F3
     CARBON(1)=CARBON(1)+F3*COIL
     HYD=HYD+F3*HOIL
     OXY=OXY+F3*O(3)/1600.
     NIT=NIT+F3*N(3)/1400.
C  INCLUDE BOTH SECONDARY OIL AIR AND SCC LEAKAGE WITH SCC COMBUST. AIR
     O2(1)=0.434/FUEL*(AIRPCC+AIRSCC+AIROIL(1)+AIROIL(2)+LEAK(1)
    1+LEAK(2))
     N2=3.76*O2(1)+NIT/2.
     CALL EQUATE
C  TOTAL HEAT RELEASED DURING COMBUSTION OF WASTE, PCC OIL, AND SCC OIL
     HTCOMB=CO2*HTCO2+H2O(2)*HTH2O(1)+CO*HTCO+HTFUEL+HTOILP+HTOILS
    1-HTLOST
C  HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER
     HTCOMB=HTCOMB-(HTPCC+HTFLME)/FUEL
     HTSCC=HTCOMB*FUEL
     GASSCC=GASPCC+OIL(2)+(AIROIL(2)+LEAK(2)+AIRSCC)*60.
     IF (TYPE.EQ.8) WRITE(6,103)
     WRITE(6,42) HTCOMB,GASSCC
C
C  SOLVE ENERGY EQUATIONS GOVERNING SECONDARY COMBUSTION CHAMBER
C  INTERIOR AND WALLS OF THE SCC SIMULTANEOUSLY...USING NEWTONS METHOD..
C  TO DETERMINE ACTUAL INCINERATOR TEMPERATURES
C
C  AGAIN, SIMPLIFY ITERATION BY COMBINING CONSTANTS
     F17=HCONV(2)*ASCC
     HTOTAL=H2O(1)+H2O(2)
     F18=-GASSCC*SPHT(TAMB,O2(2),N2,CO,H2,HTOTAL,CO2)*(TAMB-TDATUM)
    1+GASPCC*SPHT(TAMB,O2F,N2F,COF,H2F,HTOTF,CO2F)*(TAMB-TDATUM)
    2-GASPCC*SPHT(TPCC,O2F,N2F,COF,H2F,HTOTF,CO2F)*(TPCC-TDATUM)-HTSCC
     F19=ASCC*KWALL(2)
     F20=HCONV(3)*ASCC
     F21=ASCC*ESHELL*SIGMA
     F22=ASCC*(HCONV(3)+KWALL(2))
     F23=ASCC*SIGMA
C  INITIALIZE TEMPERATURES AND ITERATION PARAMETERS
     T(1)=3500.
     T(2)=3400.
     T(3)=1000.
     IF ((TYPE.EQ.1).OR.(TYPE.EQ.2).OR.(TYPE.EQ.3).OR.(TYPE.EQ.5))
    1GO TO 122
     T(2)=TSTM(3)
     T(3)=600.
 122 NN=3
     DEVMAX=T(1)
C
```

```
C  BEGIN THE ITERATION
      DO 90 I=1,ITER
      DSAVE=DEVMAX
      DEVMAX=0.
      CPS=SPHT(T(1),O2(2),N2,CO,H2,HTOTAL,CO2)
      DCPS=DCPDT(T(1),O2(2),N2,CO,H2,HTOTAL,CO2)
      ESCC=EMISS(T(1),LSCC)
      EWALL=EMISS(T(2),LSCC)
      DEWALL=DEDT(T(2),LSCC)
      DESCC=DEDT(T(1),LSCC)
C  UPDATE THE FUNCTIONS
      F(1)=GASSCC*CPS*(T(1)-TDATUM)+F23*(ESCC*T(1)**4-EWALL*T(2)**4)
     1+F17*(T(1)-T(2))+F18
      F(2)=F19*(T(2)-T(3))-F23*(ESCC*T(1)**4-EWALL*T(2)**4)-F17*
     1(T(1)-T(2))
      F(3)=F20*(T(3)-TAMB)+F21*(T(3)**4-TAMB**4)-F19*(T(2)-T(3))
C  CALCULATE THE JACOBIAN OF THE ENERGY EQUATIONS
      JSCC(1,1)=GASSCC*(CPS+DCPS*(T(1)-TDATUM))+F23*T(1)**3*(DESCC*
     1T(1)+4.*ESCC)+F17
      JSCC(1,2)=-F23*T(2)**3*(DEWALL*T(2)+4.*EWALL)-F17
      JSCC(1,3)=0.
      JSCC(2,1)=-F23*T(1)**3*(DESCC*T(1)+4.*ESCC)-F17
      JSCC(2,2)=F19+F23*T(2)**3*(DEWALL*T(2)+4.*EWALL)+F17
      JSCC(2,3)=-F19
      JSCC(3,1)=0.
      JSCC(3,2)=-F19
      JSCC(3,3)=F22+4.*F21*T(3)**3
      IF ((TYPE.EQ.1).OR.(TYPE.EQ.2).OR.(TYPE.EQ.3).OR.(TYPE.EQ.5))
     1GO TO 114
      F(2)=T(2)-TSTM(3)
      JSCC(2,1)=0.
      JSCC(2,2)=1.
      JSCC(2,3)=0.
C  INVERT THE JACOBIAN
  114 CALL MINV(JSCC,NN,D,WVSL,WVSM)
C  THEN IMPROVE ON THE TEMPERATURE ESTIMATES
      DO 80 J=1,3
      SAVE=T(J)
      DO 75 K=1,3
      T(J)=T(J)-JSCC(J,K)*F(K)
   75 CONTINUE
      DEV=ABS(T(J)-SAVE)
      IF (DEV.GT.DEVMAX) DEVMAX=DEV
   80 CONTINUE
C  CHECK TO SEE IF ITERATION IS CONVERGING
      IF (DEVMAX.LE.DSAVE) GO TO 85
      WRITE(6,26)
      WRITE(6,44)
      WRITE(6,28)
      GO TO 200
```

```
C   CHECK TO SEE IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
    85 IF (DEVMAX.LE.TOL) GO TO 95
    90 CONTINUE
       WRITE(6,26)
       WRITE(6,46) TOL,ITER
       WRITE(6,28)
    95 CONTINUE
       TSCC=T(1)
       T(1)=T(1)-460.
       TWALL(2)=T(2)-460.
       TSHELL(2)=T(3)-460.
       WRITE(6,47) T(1),TWALL(2),TSHELL(2)
       WRITE(6,49) CPS,ESCC
       IF ((TYPE.EQ.5).OR.(TYPE.EQ.6).OR.(TYPE.EQ.7)) WRITE(6,103)
       WRITE(6,43)
       WRITE(6,24) (P(I),I=1,7)
       IF ((TYPE.EQ.1).OR.(TYPE.EQ.3).OR.(TYPE.EQ.4).OR.(TYPE.EQ.7))
      1WRITE(6,104)
C   DETERMINE HEAT TRANSFER LOSS OUT THRU COMB CHAMBER WALLS
       LOSSES(6)=KWALL(2)*ASCC*(TWALL(2)-TSHELL(2))
C
C   DETERMINE STEAM GENERATED IN CONVECTION BOILER
C   ASSUME THAT THE BOILER OVERALL HEAT TRANSFER COEFFICIENT VARIES AS
C   THE 0.6 POWER OF THE GAS SIDE REYNOLDS NO. BASED ON AVERAGE TEMPS...
C   THE CONSTANT OF PROPORTIONALITY CAN BE DETERMINED FROM CONDITIONS
C   AT THE DESIGN POINT
       IF (TYPE.EQ.1) GO TO 200
C   DETERMINE THE TOTAL GAS FLOW THRU THE BOILER
       GASOUT=GASSCC+LEAK(3)*60.
C   AND THE COMPOSITION OF THIS GAS
       O2(1)=O2(1)+0.434*LEAK(3)/FUEL
       N2=3.76*O2(1)+NIT/2.
       CALL EQUATE
C
C   SOLVE, SIMULTANEOUSLY, THE ENERGY EQUATIONS GOVERNING THE GAS FLOW
C   THRU THE BOILER, THE STEAM FLOW THRU THE BOILER, AND THE OVERALL
C   BOILER....AGAIN USE NEWTONS METHOD
C
C   SIMPLIFY ITERATION BY COMBINING CONSTANTS
       F24=GASSCC*CPS*(TSCC-TDATUM)+14.4*LEAK(3)*(TAMB-TDATUM)
       F25=(1.+BD(1))*(HSTM(1)-HFEED(1))
C   DETERMINE TEMP OF COMBUSTION GASES DILUTED BY DUMP STACK AIR LEAKAGE
       IF (LEAK(3).LE.0.) GO TO 99
       DEV=TSCC
       DO 98 I=1,ITER
       CPS=SPHT(TSCC,O2(2),N2,CO,H2,HTOTAL,CO2)
       DCPS=DCPDT(TSCC,O2(2),N2,CO,H2,HTOTAL,CO2)
       F(1)=GASOUT*CPS*(TSCC-TDATUM)-F24
       DFDT=GASOUT*(CPS+DCPS*(TSCC-TDATUM))
       DEVOLD=DEV
       TSCC=TSCC-F(1)/DFDT
```

```
C  CHECK TO SEE IF ITERATION IS CONVERGING
      DEV=ABS(F(1)/DFDT)
      IF (DEV.LE.DEVOLD) GO TO 97
      WRITE(6,26)
      WRITE(6,57)
      WRITE(6,28)
      GO TO 200
C  CHECK TO SEE IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
   97 IF (DEV.LE.TOL) GO TO 99
   98 CONTINUE
      WRITE(6,26)
      WRITE(6,58) TOL,ITER
      WRITE(6,28)
   99 CONTINUE
      IF ((TYPE.EQ.3).OR.(TYPE.EQ.7)) GO TO 117
      IF (TYPE.EQ.4) GO TO 118
      IF (TSCC.GT.TSTM(1)) GO TO 102
      WRITE(6,26)
      WRITE(6,96)
      WRITE(6,28)
      GO TO 200
C  THE EUCKEN EQUATIONS WILL BE USED TO DESCRIBE THE VARIATION OF BOTH
C  THERMAL CONDUCTIVITY AND VISCOSITY WITH TEMPERATURE
  102 TAVG=0.25*(TIN+TFEED(1)+TOUT+TSTM(1))
      FACTOR=TAVG**1.5/(225.+TAVG)
      KF=9.986E-4*FACTOR
      MUF=2.694E-3*FACTOR
      UCONST=U/KF/(FLOW/MUF)**0.6
C  INITIALIZE TOTAL HEAT TRANSFER, STEAM GENERATION RATE, AND TEMP OF
C  STACK GASES....ALSO INITIALIZE ITERATION PARAMETERS
      QSTM=1.2E7
      STEAM(1)=10000.
      TSTACK=1000.
      DEV=TSTACK
C
C  BEGIN THE ITERATION
      DO 110 I=1,ITER
      DSAVE=DEV
      CPGAS=SPHT(TSTACK,O2(2),N2,CO,H2,HTOTAL,CO2)
      DCPGAS=DCPDT(TSTACK,O2(2),N2,CO,H2,HTOTAL,CO2)
      TAVG=0.25*(TSCC+TFEED(1)+TSTACK+TSTM(1))
      FACTOR=TAVG**1.5/(225.+TAVG)
      KF=9.986E-4*FACTOR
      MUF=2.694E-3*FACTOR
      U=UCONST*KF*(GASOUT/MUF)**0.6
      FACTOR=1.5*SQRT(TAVG)/(225.+TAVG)-TAVG**1.5/(225.+TAVG)**2
      DKFDT=9.986E-4*FACTOR
      DMUDT=2.694E-3*FACTOR
      DUDT=0.25*UCONST*(GASOUT/MUF)**0.6*(DKFDT-0.6*KF/MUF*DMUDT)
      FACTOR=ALOG((TSCC-TSTM(1))/(TSTACK-TFEED(1)))
```

```
C  UPDATE THE FUNCTIONS
      F(1)=GASOUT*CPGAS*(TSTACK-TDATUM)+QSTM-F24
      F(2)=STEAM(1)*F25-QSTM
      F(3)=U*ABOIL*(TSCC-TSTM(1)-TSTACK+TFEED(1))/FACTOR-QSTM
C  CALCULATE THE JACOBIAN OF THE ENERGY EQUATIONS
      JBOIL(1,1)=1.
      JBOIL(1,2)=0.
      JBOIL(1,3)=GASOUT*(CPGAS+DCPGAS*(TSTACK-TDATUM))
      JBOIL(2,1)=-1.
      JBOIL(2,2)=F25
      JBOIL(2,3)=0.
      JBOIL(3,1)=-1.
      JBOIL(3,2)=0.
      JBOIL(3,3)=ABOIL/FACTOR*(DUDT*(TSCC-TSTM(1)-TSTACK+TFEED(1))-U+U*
     1((TSCC-TSTM(1))/(TSTACK-TFEED(1))-1.)/FACTOR)
C  INVERT THE JACOBIAN
      CALL MINV(JBOIL,NN,D,WVSL,WVSM)
C  THEN IMPROVE ON THE UNKNOWNS
      SAVE=TSTACK
      DO 100 K=1,3
      QSTM=QSTM-JBOIL(1,K)*F(K)
      STEAM(1)=STEAM(1)-JBOIL(2,K)*F(K)
      TSTACK=TSTACK-JBOIL(3,K)*F(K)
  100 CONTINUE
      DEV=ABS(TSTACK-SAVE)
C  CHECK TO SEE IF ITERATION IS CONVERGING
      IF (DEV.LE.DSAVE) GO TO 105
      WRITE(6,26)
      WRITE(6,51)
      WRITE(6,28)
      GO TO 200
C  CHECK TO SEE IF ITERATION HAS CONVERGED TO WITHIN TOLERANCE
  105 IF (DEV.LE.TOL) GO TO 115
  110 CONTINUE
      WRITE(6,26)
      WRITE(6,56) ITER
      WRITE(6,28)
  115 CONTINUE
C  CALCULATE BOILER EFFICIENCY USING SUMMATION OF LOSSES METHOD
C  USE ENTHALPY DATUM AT 60.DEGF TO BE CONSISTENT WITH COMB. PRODUCTS
      INPUT(4)=STEAM(1)*(1.+BD(1))*(HFEED(1)-HDATUM)
      LOSSES(8)=GASOUT*CPGAS*(TSTACK-TDATUM)
      LOSSES(9)=STEAM(1)*(BD(1)/(1.-BD(1)))*(HSTM(1)-HDATUM)
      EFF=1.-(LOSSES(8)+LOSSES(9))/(GASOUT*CPS*(TSCC-TDATUM)+INPUT(4))
      OUTPUT=STEAM(1)*(HSTM(1)-HFEED(1))
      TSCC=TSCC-460.
      TSTACK=TSTACK-460.
      WRITE(6,52) GASOUT,TSCC,TSTACK
      TSCC=TSCC+460.
      TSTACK=TSTACK+460.
      WRITE(6,53)
      WRITE(6,24) (P(I),I=1,7)
      WRITE(6,54) STEAM(1),QSTM,U,EFF
      IF (TYPE.EQ.2) GO TO 119
C
```

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C  DETERMINE STEAM GENERATED IN PCC WATER-WALL BOILER
  117 IF (TYPE.EQ.6) GO TO 118
      QTOTAL=QCONV+QRAD1+QRAD2
      RATIO(1)=100.*QCONV/QTOTAL
      RATIO(2)=100.*QRAD1/QTOTAL
      RATIO(3)=100.*QRAD2/QTOTAL
      STEAM(2)=(QTOTAL-QCOND)/(HSTM(2)-HFEED(2))
      OUTPUT=OUTPUT+STEAM(2)*(HSTM(2)-HFEED(2))
      WRITE(6,88)
      WRITE(6,89) STEAM(2),QTOTAL,QCONV,RATIO(1),QRAD1,RATIO(2),QRAD2
     1,RATIO(3),QCOND
C  CALCULATE BOILER EFFICIENCY USING SUMMATION OF LOSSES METHOD
      INPUT1=HTFLME+HTPCC+0.24*GASPCC*(TAMB-TDATUM)
      INPUT4=STEAM(2)*(1.+BD(2))*(HFEED(2)-HDATUM)
      LOSS8=GASPCC*CPP*(TPCC-TDATUM)
      LOSS9=STEAM(2)*(BD(2)/(1.-BD(2)))*(HSTM(2)-HDATUM)
      EFF=1.-(LOSSES(5)+LOSS8+LOSS9)/(INPUT1+INPUT4)
      WRITE(6,94) EFF
      INPUT(4)=INPUT(4)+INPUT4
      LOSSES(9)=LOSSES(9)+LOSS9
      IF ((TYPE.EQ.3).OR.(TYPE.EQ.5)) GO TO 119
C
C  DETERMINE STEAM GENERATED IN SCC WATER-WALL BOILER
  118 QCONV=F17*(TSCC-T(2))
      QRAD2=F23*(ESCC*TSCC**4-EWALL*T(2)**4)
      QCOND=F19*(T(2)-T(3))
      QTOTAL=QCONV+QRAD2
      RATIO(1)=100.*QCONV/QTOTAL
      RATIO(3)=100.*QRAD2/QTOTAL
      STEAM(3)=(QTOTAL-QCOND)/(HSTM(3)-HFEED(3))
      OUTPUT=OUTPUT+STEAM(3)*(HSTM(3)-HFEED(3))
      WRITE(6,91)
      WRITE(6,92) STEAM(3),QTOTAL,QCONV,RATIO(1),QRAD2,RATIO(3),QCOND
C  CALCULATE BOILER EFFICIENCY USING SUMMATION OF LOSSES METHOD
      AIR=60.*(AIRPCC+AIRSCC+AIROIL(1)+AIROIL(2)+LEAK(1)+LEAK(2))
      INPUT1=HTSCC+0.24*(GASSCC-AIR)*(TAMB-TDATUM)
      INPUT2=GASPCC*CPP*(TPCC-TDATUM)
      INPUT4=STEAM(3)*(1.+BD(3))*(HFEED(3)-HDATUM)
      LOSS8=GASSCC*CPS*(TSCC-TDATUM)
      LOSS9=STEAM(3)*(BD(3)/(1.-BD(3)))*(HSTM(3)-HDATUM)
      EFF=1.-(LOSSES(6)+LOSS8+LOSS9)/(INPUT1+INPUT2+INPUT4)
      WRITE(6,94) EFF
      INPUT(4)=INPUT(4)+INPUT4
      LOSSES(9)=LOSSES(9)+LOSS9
C
C  CALCULATE THE OVERALL EFFICIENCY OF THE HEAT RECOVERY INCINERATOR
C  FIRST, USE THE STRAIGHT INPUT-OUTPUT METHOD
  119 INPUT(1)=FUEL*HHV(1)
      INPUT(3)=(OIL(1)+OIL(2))*HHV(3)
      INPUT(5)=3415.*KW
      EFF=OUTPUT/(INPUT(1)+INPUT(3)+INPUT(5))
      WRITE(6,59)
      WRITE(6,61) INPUT(1),INPUT(3),INPUT(5),OUTPUT,EFF
```

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C  SECOND, USE THE SUMMATION OF LOSSES METHOD
      TOTAL1=0.
      TOTAL2=0.
      EFF=1.
C  BEGIN BY DOCUMENTING ALL ENERGY INPUTS TO THE INCINERATOR SYSTEM
      AIR=AIRPCC+AIRSCC+AIROIL(1)+AIROIL(2)+LEAK(1)+LEAK(2)+LEAK(3)
      INPUT(2)=14.4*AIR*(TAMB-TDATUM)
C  DELETE SENSIBLE ENERGY OF AIR FROM MEASURED HEATING VALUE OF FUEL
      INPUT(1)=INPUT(1)-INPUT(2)+0.24*GASOUT*(TAMB-TDATUM)
      DO 120 I=1,5
      TOTAL1=TOTAL1+INPUT(I)
  120 CONTINUE
C  THEN DOCUMENT ALL ENERGY LOSSES FROM THE INCINERATOR SYSTEM
      LOSSES(1)=HTLOST*FUEL
      LOSSES(2)=18.*H2O(2)*HFG*FUEL
      LOSSES(3)=C(2)*ASH*HTCO2/1200.
      LOSSES(4)=0.2*ASH*(TFLAME(2)-TDATUM)
      LOSSES(7)=FUEL*(CO*(HTCO2-HTCO)+CARBON(2)*HTCO2+H2*HTH2O(2))
      IF ((TYPE.EQ.3).OR.(TYPE.EQ.4).OR.(TYPE.EQ.7))
     1LOSSES(8)=GASOUT*CPS*(TSCC-TDATUM)
      LOSSES(10)=INPUT(5)
      DO 125 I=1,5
      RATIO(I)=INPUT(I)/TOTAL1
  125 CONTINUE
      DO 130 I=6,15
      RATIO(I)=LOSSES(I-5)/TOTAL1
      EFF=EFF-RATIO(I)
      TOTAL2=TOTAL2+LOSSES(I-5)
  130 CONTINUE
      RATIO(16)=TOTAL2/TOTAL1
      IF (TYPE.EQ.7) WRITE(6,103)
      WRITE(6,62)
      WRITE(6,63)
      WRITE(6,64) (INPUT(I),RATIO(I),I=1,5)
      WRITE(6,66) TOTAL1
      WRITE(6,67)
      WRITE(6,68) (LOSSES(I),RATIO(I+5),I=1,4)
      WRITE(6,69) (LOSSES(I),RATIO(I+5),I=5,10)
      WRITE(6,71) TOTAL2,RATIO(16)
      WRITE(6,72) EFF
C
  200 CONTINUE
      STOP
    1 FORMAT(2F10.0)
    2 FORMAT(5F10.3)
    3 FORMAT(4F10.3)
    4 FORMAT(3F10.0)
    5 FORMAT(F10.0)
    6 FORMAT(8F10.0)
    9 FORMAT(1H ,10X,"FUEL (WASTE) MASS FEED RATE = ",F6.0," LB/HR WET",
     1/11X,"HIGHER HEATING VALUE OF FUEL = ",F6.0," BTU/LB DRY"/)
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10 FORMAT(1H ,10X,"ULTIMATE ANALYSIS OF FUEL",20X,"PROXIMATE ANALYSIS
  1 OF FUEL",/12X,"(PERCENT OF DRY WEIGHT)",25X,"(PERCENT OF WEIGHT)"
  2,/11X,"CARBON.......   ",F5.2,24X,"MOISTURE.........   ",F5.2,/11X
  3,"HYDROGEN.....   ",F5.2,24X"VOLATILE MATTER..   ",F5.2,/11X, "OXY
  4GEN.......   ",F5.2,24X,"FIXED CARBON.....   ",F5.2,/11X,"NITROGEN
  5.....   ",F5.2,24X,"ASH.............   ",F5.2,/11X,"OTHER........
  6   ",F5.2//)
11 FORMAT(1H ,10X,"ASH REMOVAL RATE = ",F5.0," LB/HR",/11X,"HIGHER HE
  1ATING VALUE OF ASH = ",F5.0," BTU/LB"/)
13 FORMAT(1H ,10X,"CARBON.......   ",F5.2,/11X,"HYDROGEN.....   ",F5.
  12,/11X,"OXYGEN.......   ",F5.2,/11X,"NITROGEN.....   ",F5.2,/11X,"
  2OTHER........   ",F5.2//)
14 FORMAT(1H ,10X,"OIL FLOW TO PRIMARY COMBUSTION CHAMBER = ",F5.0,"
  1LB/HR",/11X,"OIL FLOW TO SECONDARY COMBUSTION CHAMBER = ",F5.0," L
  2B/HR",/11X,"HIGHER HEATING VALUE OF OIL = ",F6.0," BTU/LB"/)
15 FORMAT(1H ,10X,"ULTIMATE ANALYSIS OF OIL",/12X,"(PERCENT OF DRY WE
  1IGHT)")
16 FORMAT(1H ,10X,"COMBUSTION AIR",/13X,"TO PRIMARY COMBUSTION CHAMBE
  1R (UNDERFIRE) = ",F5.0," LB/MIN",/13X,"TO PRIMARY COMBUSTION CHAMB
  2ER (OVERFIRE) = ",F5.0," LB/MIN",/13X,"TO SECONDARY COMBUSTION CHA
  3MBER = ",F5.0," LB/MIN",/13X,"TO (WITH) PRIMARY OIL BURNER = ",F5.
  40," LB/MIN",/13X,"TO (WITH) SECONDARY OIL BURNER = ",F5.0," LB/MIN
  5"/)
17 FORMAT(1H ,10X,"LEAKAGE AIR",/13X,"TO PRIMARY COMBUSTION CHAMBER =
  1 ",F4.0," LB/MIN",/13X,"TO SECONDARY COMBUSTION CHAMBER = ",F4.0,"
  2 LB/MIN",/13X,"DOWN THE DUMP STACK = ",F4.0," LB/MIN"/)
18 FORMAT(1H ,10X,"AMBIENT AIR TEMPERATURE = ",F4.0," DEGF"///)
19 FORMAT(1H ,5X,"HEAT TRANSFER PARAMETERS",/11X,"SURFACE AREA OF FLA
  1ME FRONT =",F5.0," SQFT",/11X,"SURFACE AREA OF PCC = ",F5.0," SQFT
  2",/11X,"SURFACE AREA OF SCC = ",F5.0," SQFT")
20 FORMAT(1H ,5X,"CONVECTION BOILER CHARACTERISTICS",/11X,"SURFACE AR
  1EA OF TUBES =",F6.0," SQFT",/11X,"FEED WATER PROPERTIES",/13X,"TEM
  2PERATURE = ",F4.0," DEGF",/13X,"ENTHALPY = ",F4.0," BTU/LB",/11X,"
  3STEAM PROPERTIES",/13X,"TEMPERATURE = ",F4.0," DEGF",/13X,"PRESSUR
  4E = ",F4.0," PSIA",/13X,"ENTHALPY = ",F5.0," BTU/LB (VAPOR)",/13X,
  5"ENTHALPY = ",F5.0," BTU/LB (LIQUID)",/11X,"BOILER BLOW-DOWN = ",F
  64.1," PERCENT OF STEAM GENERATED")
21 FORMAT(1H ,10X,"OVERALL HEAT TRANSFER COEFFICIENT = "F6.2," BTU/HR
  1-SQFT-DEGF AT THE DESIGN POINT"//)
22 FORMAT(1H0,5X,"AIR REQUIRED FOR STOICHIOMETRIC COMBUSTION OF SOLID
  1 WASTE = ",F7.2," LB/MIN",/6X,"HEAT ABSORBED IN BREAKING DOWN FUEL
  2 = ",F6.0," BTU/LB")
23 FORMAT(1H0,5X,"PRODUCTS OF COMBUSTION OF SOLID WASTE WITH STOICHIO
  1METRIC AIR")
24 FORMAT(1H ,10X,"(LBS/LB OF DRY FUEL)",/6X,"CARBON DIOXIDE....    ",
  1F7.4, /6X,"WATER VAPOR.......    ",F7.4,/6X,"CARBON MONOXIDE...    "
  2,F7.4,/6X,"OXYGEN...........    ",F7.4,/6X,"NITROGEN..........    "
  3,F7.4,/6X,"HYDROGEN..........    ",F7.4,/6X,"CARBON............    "
  4,F7.4//)
26 FORMAT(1H0,///6X,"***********************************************
  1*************************************************************"/)
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27 FORMAT(1H ,5X,"ITERATION FOR ADIABATIC FLAME TEMPERATURE IS DIVERG
  1ING, ANALYSIS IS TERMINATED"/)
28 FORMAT(1H ,5X,"****************************************************
  1*************************************************************"/)
29 FORMAT(1H ,4X," SOLUTION FOR ADIABATIC FLAME TEMPERATURE DID NOT C
  1ONVERGE TO WITHIN ",F2.0," DEGF AFTER ",I3," ITERATIONS"/)
30 FORMAT(1H0,5X,"FUEL (WASTE) MASS FEED RATE = ",F5.0," LB/HR DRY",/
  16X,"HEAT RELEASED IN FLAME ZONE = ",E10.4," BTU/LB OF DRY FUEL",/6
  2X,"HEAT LOST VAPORIZING THE MOISTURE IN THE FUEL = ",E10.4," BTU/L
  3B OF DRY FUEL",/6X,"TOTAL GAS FLOW THRU THE FLAME = ",E10.4," LB/H
  4R",/6X,"THEORETICAL (ADIABATIC) FLAME TEMPERATURE = ",F5.0," DEGF"
  5/)
31 FORMAT(1H ,5X,"PRODUCTS OF COMBUSTION OF SOLID WASTE IN FLAME ZONE
  1")
32 FORMAT(1H0,/6X,"HEAT RELEASED IN PRIMARY COMBUSTION CHAMBER = ",E1
  10.4," BTU/LB OF DRY FUEL",/6X,"TOTAL GAS FLOW THRU PRIMARY COMBUST
  2ION CHAMBER = ",E10.4," LB/HR")
33 FORMAT(1H ,5X,"PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN TH
  1E PRIMARY COMBUSTION CHAMBER")
34 FORMAT(1H ,10X,"EMISSIVITY OF OUTER SURFACE OF INCINERATOR = ",F4.
  12)
36 FORMAT(1H1,  9X," CONVECTION FILM COEFFICIENTS",/13X,"INNER SURFAC
  1E OF PCC = ",F4.0," BTU/HR-SQFT-DEGF",/13X,"INNER SURFACE OF SCC =
  2 ",F4.0," BTU/HR-SQFT-DEGF",/13X,"OUTER SURFACE OF INCINERATOR = "
  3,F4.0," BTU/HR-SQFT-DEGF",/11X,"THERMAL CONDUCTANCE THRU WALLS",/1
  43X,"OF PRIMARY COMBUSTION CHAMBER = ",F5.3," BTU/HR-SQFT-DEGF",/13
  5X,"OF SECONDARY COMBUSTION CHAMBER = ",F5.3," BTU/HR-SQFT-DEGF",/1
  61X,"MEAN BEAM LENGTH",/13X,"OF PRIMARY COMBUSTION CHAMBER = ",F5.2
  7," FT",/13X,"OF SECONDARY COMBUSTION CHAMBER = ",F5.2," FT"///)
37 FORMAT(1H ,5X,"ITERATION FOR GAS TEMPERATURE IN THE PRIMARY COMBUS
  1TION CHAMBER IS DIVERGING, ANALYSIS IS TERMINATED"/)
38 FORMAT(1H ,5X,"SOLUTION FOR PRIMARY COMBUSTION CHAMBER TEMPERATURE
  1S DID NOT CONVERGE TO WITHIN ",F2.0," DEGF AFTER ",I3," ITERATIONS
  2"/)
39 FORMAT(1H ,5X,"HOMOGENEOUS FLAME TEMPERATURE = ",F5.0," DEGF"/)
41 FORMAT(1H ,5X,"HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN PRIM
  1ARY COMBUSTION CHAMBER = ",F5.0," DEGF",/6X,"PRIMARY COMBUSTION CH
  2AMBER INSIDE WALL TEMPERATURE = ",F5.0," DEGF",/6X,"PRIMARY COMBUS
  3TION CHAMBER OUTSIDE WALL TEMPERATURE = ",F5.0," DEGF"/)
42 FORMAT(1H0,5X,"HEAT RELEASED IN SECONDARY COMBUSTION CHAMBER = ",E
  110.4," BTU/LB OF DRY FUEL",/6X,"TOTAL GAS FLOW THRU SECONDARY COMB
  2USTION CHAMBER = ",E10.4," LB/HR")
43 FORMAT(1H ,5X,"PRODUCTS OF COMBUSTION OF SOLID WASTE AND OIL IN TH
  1E SECONDARY COMBUSTION CHAMBER")
44 FORMAT(1H ,5X,"ITERATION FOR GAS TEMPERATURE IN THE SECONDARY COMB
  1USTION CHAMBER IS DIVERGING, ANALYSIS IS TERMINATED"/)
46 FORMAT(1H ,5X,"SOLUTION FOR SECONDARY COMBUSTION CHAMBER TEMPERATU
  1RES DID NOT CONVERGE TO WITHIN ",F2.0," DEGF AFTER ",I3," ITERATIO
  2NS"/)
47 FORMAT(1H ,5X,"HOMOGENEOUS TEMPERATURE OF COMBUSTION GASES IN SECO
  1NDARY COMBUSTION CHAMBER = ",F5.0," DEGF",/6X,"SECONDARY COMBUSTIO
  2N CHAMBER INSIDE WALL TEMPERATURE = ",F5.0," DEGF",/6X,"SECONDARY
  3COMBUSTION CHAMBER OUTSIDE WALL TEMPERATURE = ",F5.0," DEGF"/)
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48 FORMAT(1H ,5X,"SPECIFIC HEAT OF PCC COMBUSTION PRODUCTS = ",F4.2,"
  1 BTU/LB-DEGF",/6X,"EMISSIVITY OF PCC COMBUSTION PRODUCTS =",F6.3/)
49 FORMAT(1H ,5X,"SPECIFIC HEAT OF SCC COMBUSTION PRODUCTS = ",F4.2,"
  1 BTU/LB-DEGF",/6X,"EMISSIVITY OF SCC COMBUSTION PRODUCTS =",F6.3/)
51 FORMAT(1H ,5X,"THE ITERATION FOR THE CONVECTION BOILER PERFORMANCE
  1 IS DIVERGING, ANALYSIS IS TERMINATED"/)
52 FORMAT(1H0,5X,"TOTAL GAS FLOW OUT THE STACK = ",E10.4," LB/HR",/6X
  1,"TEMPERATURE OF COMBUSTION GASES ENTERING THE BOILER = ",F5.0," D
  2EGF",/6X,"STACK GAS TEMPERATURE = ",F5.0," DEGF"/)
53 FORMAT(1H ,5X,"COMPOSITION OF STACK GASES")
54 FORMAT(1H ,5X,"CONVECTION BOILER",//11X,"STEAM GENERATION = ",F6.0
  1," LB/HR",//11X,"BOILER HEAT TRANSFER RATE = ",E10.4," BTU/HR",/11
  2X,"BOILER OVERALL HEAT TRANSFER COEFFICIENT = ",F6.2," BTU/HR-SQFT
  3-DEGF",//11X,"THERMAL EFFICIENCY OF BOILER = ",F4.2//)
56 FORMAT(1H ,5X,"SOLUTION FOR THE PERFORMANCE OF THE BOILER HAS NOT
  1CONVERGED AFTER ",I3," ITERATIONS"/)
57 FORMAT(1H ,5X,"THE ITERATION FOR TEMP OF THE GAS ENTERING THE BOIL
  1ER IS DIVERGING, ANALYSIS IS TERMINATED"/)
58 FORMAT(1H ,5X,"SOLUTION FOR BOILER INLET GAS TEMPERATURE HAS NOT C
  1ONVERGED TO WITHIN ",F2.0," DEGF AFTER ",I3," ITERATIONS"/)
59 FORMAT(1H0,5X,"OVERALL EFFICIENCY OF HEAT RECOVERY INCINERATOR"/)
61 FORMAT(1H ,10X,"USING THE DIRECT METHOD",//14X,"INPUT = ",E10.4,"
  1BTU/HR OF WASTE (HHV*DRY FEED RATE)",/20X,"+ ",E10.4," BTU/HR OF O
  2IL (HHV*FLOW RATE)",/20X,"+ ",E10.4," BTU/HR FROM MISCELLANEOUS AC
  3CESSORIES",/14X,"OUTPUT = ",E10.4," BTU/HR TO STEAM",//14X,"EFFICI
  4ENCY = OUTPUT/INPUT = ",F4.2//)
62 FORMAT(1H ,10X,"USING THE SUMMATION OF LOSSES METHOD"/)
63 FORMAT(1H ,26X,"INPUT",34X,"BTU/HR",15X,"FRACTION OF TOTAL INPUT")
64 FORMAT(1H ,13X,"CHEMICAL + SENSIBLE ENERGY OF WASTE FUEL.....    "
  1,E10.4,20X,F6.4,/14X,"ENTHALPY OF COMBUSTION AIR.................
  2.    ",E10.4,20X,F6.4,/14X,"CHEMICAL + SENSIBLE ENERGY OF OIL.....
  3.......    ",E10.4,20X,F6.4,/14X,"ENTHALPY OF BOILER FEED WATER...
  4.............    ",E10.4,20X,F6.4,/14X,"POWER REQUIRED TO RUN ACCE
  5SSORIES...........    ",E10.4,20X,F6.4/)
66 FORMAT(1H ,13X,"TOTAL INPUT TO HRI SYSTEM...................    "
  1,E10.4//)
67 FORMAT(1H ,26X,"LOSSES",33X,"BTU/HR",15X,"FRACTION OF TOTAL INPUT"
  1)
68 FORMAT(1H ,13X,"VAPORIZATION OF MOISTURE WITH WASTE..........    "
  1 ,E10.4,20X,F6.4,/14X,"VAPOR. OF H2O GEN. BY BURNING H2 IN WASTE..
  2..    ",E10.4,20X,F6.4,/14X,"CARBON CARRIED OUT WITH ASH..........
  3.......    ",E10.4,20X,F6.4,/14X,"SENSIBLE HEAT IN ASH...........
  4..............    ",E10.4,20X,F6.4)
69 FORMAT(1H ,13X,"HEAT TRANSFER THRU WALLS OF PCC.............    "
  1,E10.4,20X,F6.4,/14X,"HEAT TRANSFER THRU WALLS OF SCC............
  2.    ",E10.4,20X,F6.4,/14X,"INCOMPLETE COMBUSTION................
  3......    ",E10.4,20X,F6.4,/14X,"SENSIBLE HEAT IN STACK GASES....
  4.............    ",E10.4,20X,F6.4,/14X,"LOSS OF STEAM DUE TO BLOW-
  5DOWN...............    ",E10.4,20X,F6.4,/14X,"POWER REQUIRED TO RU
  6N ACCESSORIES...........    ",E10.4,20X,F6.4/)
71 FORMAT(1H ,13X,"TOTAL LOSSES FROM HRI SYSTEM................    "
  1,E10.4,20X,F6.4//)
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 72 FORMAT(1H ,13X,"EFFICIENCY = 1.-(TOTAL LOSSES)/(TOTAL INPUT) = ",F
   14.2)
 73 FORMAT(1H1,5X,"FEED RATES AND BOUNDARY CONDITIONS"/)
 74 FORMAT(1H ,10X,"ULTIMATE ANALYSIS OF ASH",/12X,"(PERCENT OF DRY WE
   1IGHT)")
 76 FORMAT(1H ,5X,"INCINERATOR HAS NO BOILERS"//)
 77 FORMAT(1H ,5X,"HRI HAS A CONVECTION TYPE BOILER AT THE SCC EXIT"//
   1)
 78 FORMAT(1H ,5X,"HRI HAS A PCC WATER-WALL BOILER"//)
 79 FORMAT(1H ,5X,"HRI HAS A SCC WATER-WALL BOILER"//)
 81 FORMAT(1H ,5X,"HRI HAS BOTH A PCC WATER-WALL AND CONVECTION TYPE B
   1OILER"//)
 82 FORMAT(1H ,5X,"HRI HAS BOTH A SCC WATER-WALL AND CONVECTION TYPE B
   1OILER"//)
 83 FORMAT(1H ,5X,"HRI HAS BOTH PCC AND SCC WATER-WALLS"//)
 84 FORMAT(1H ,5X,"HRI HAS PCC AND SCC WATER-WALLS AND ALSO A CONVECTI
   1ON TYPE BOILER"//)
 86 FORMAT(1H ,5X,"PRIMARY COMBUSTION CHAMBER WATER-WALL BOILER CHARAC
   1TERISTICS",/11X,"SURFACE AREA OF WATER-WALL = ",F4.0," SQFT",/11X,
   2"FEED WATER PROPERTIES",/13X,"TEMPERATURE = ",F4.0," DEGF",/13X,"E
   3NTHALPY = ",F4.0," BTU/LB",/11X,"STEAM PROPERTIES",/13X,"TEMPERATU
   4RE = ",F4.0," DEGF",/13X,"PRESSURE = ",F4.0," PSIA",/13X,"ENTHALPY
   5 = ",F5.0," BTU/LB",/11X,"BOILER BLOW-DOWN = ",F4.1," PERCENT OF S
   6TEAM GENERATED"//)
 87 FORMAT(1H ,5X,"SECONDARY COMBUSTION CHAMBER WATER-WALL BOILER CHAR
   1ACTERISTICS",/11X,"SURFACE AREA OF WATER-WALL = ",F4.0," SQFT",/11
   2X,"FEED WATER PROPERTIES",/13X,"TEMPERATURE = ",F4.0," DEGF",/13X,
   3"EHTHALPY = ",F4.0," BTU/LB",/11X,"STEAM PROPERTIES",/13X,"TEMPERA
   4TURE = ",F4.0," DEGF",/13X,"PRESSURE = ",F4.0," PSIA",/13X,"ENTHAL
   5PY = ",F5.0," BTU/LB",/11X,"BOILER BLOW-DOWN = ",F4.1," PERCENT OF
   6 STEAM GENERATED"//)
 88 FORMAT(1H ,5X,"PRIMARY COMBUSTION CHAMBER WATER-WALL BOILER"/)
 89 FORMAT(1H ,10X,"STEAM GENERATION = ",F6.0," LB/HR",//11X,"TOTAL HE
   1AT TRANSFERRED TO WALLS = ",E10.4," BTU/HR",/13X,"BY CONVECTION FR
   2OM PRODUCTS OF COMBUSTION = ",E10.4," BTU/HR (",F4.1," PERCENT OF
   3TOTAL)",/13X,"BY RADIATION FROM FLAME = ",E10.4," BTU/HR (",F4.1,"
   4 PERCENT OF TOTAL)",/13X,"BY RADIATION FROM PRODUCTS OF COMBUSTION
   5 = ",E10.4," BTU/HR (",F4.1," PERCENT OF TOTAL)",/11X,"HEAT LOST B
   6Y CONDUCTION OUT THRU THE WALLS = ",E10.4," BTU/HR"/)
 91 FORMAT(1H ,5X,"SECONDARY COMBUSTION CHAMBER WATER-WALL BOILER"/)
 92 FORMAT(1H ,10X,"STEAM GENERATION = ",F6.0," LB/HR",//11X,"TOTAL HE
   1AT TRANSFERRED TO WALLS = ",E10.4," BTU/HR",/13X,"BY CONVECTION FR
   2OM PRODUCTS OF COMBUSTION = ",E10.4," BTU/HR (",F4.1," PERCENT OF
   3TOTAL)",/13X,"BY RADIATION FROM PRODUCTS OF COMBUSTION = ",E10.4,"
   4 BTU/HR (",F4.1," PERCENT OF TOTAL)",/11X,"HEAT LOST BY CONDUCTION
   5 OUT THRU THE WALLS = ",E10.4," BTU/HR"/)
 93 FORMAT(I5)
 94 FORMAT(1H ,10X,"THERMAL EFFICIENCY OF BOILER = ",F4.2//)
 96 FORMAT(1H ,5X,"THE CONVECTION BOILER STEAM TEMPERATURE IS GREATER
   1THAN THE TEMPERATURE OF THE COMBUSTION PRODUCTS, ANALYSIS IS TERMI
   2NATED"/)
103 FORMAT(1H1)
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  104 FORMAT(1H ,5X,"THE STACK GAS PROPERTIES ARE APPROXIMATELY EQUAL TO
     1 THE SECONDARY COMBUSTION CHAMBER PROPERTIES"//)
      END
      FUNCTION SPHT(T,O2,N2,CO,H2,H2O,CO2)
C  PROGRAM TO CALCULATE THE MEAN SPECIFIC HEAT BETWEEN T AND 60 DEGF
C  OF A MIXTURE OF GASES....THE GASES CONSIDERED ARE OXYGEN, NITROGEN
C  CARBON MONOXIDE, HYDROGEN, WATER VAPOR, AND CARBON DIOXIDE
C  SPECIFIC HEAT CALCULATED IN BTU/LB-DEGF
      REAL MW,MOLES,N2
      DIMENSION CP(6)
      DATA TDATUM/520./
      SPHT=0.
      DELTA=T-TDATUM
C  FIRST CALCULATE THE MEAN SPECIFIC HEAT OF INDIVIDUAL COMPONENTS
C  USING THE RELATIONSHIPS OF SWEIGERT AND BEARDSLEY, REF. GEORGIA
C  INST. OF TECH. BULLETIN 2 (1938)
      CP(1)=(11.515*DELTA-344.*(SQRT(T)-SQRT(TDATUM))+1530.
     1*(ALOG(T)-ALOG(TDATUM)))/DELTA*O2
      CP(2)=(9.47*DELTA-3.47E3*(ALOG(T)-ALOG(TDATUM))-1.16E6
     1*(1./T-1./TDATUM))/DELTA*N2
      CP(3)=(9.46*DELTA-3.29E3*(ALOG(T)-ALOG(TDATUM))-1.07E6
     1*(1./T-1./TDATUM))/DELTA*CO
      CP(4)=(5.76*DELTA+2.89E-4*(T**2-TDATUM**2)+40.*(SQRT(T)
     1-SQRT(TDATUM)))/DELTA*H2
      CP(5)=(19.86*DELTA-1194.*(SQRT(T)-SQRT(TDATUM))+7500.
     1*(ALOG(T)-ALOG(TDATUM)))/DELTA*H2O
      CP(6)=(16.2*DELTA-6.53E3*(ALOG(T)-ALOG(TDATUM))-1.41E6
     1*(1./T-1./TDATUM))/DELTA*CO2
C  THE TOTAL NUMBER OF MOLES IN THE MIXTURE
      MOLES=O2+N2+CO+H2+H2O+CO2
C  THE MOLECULAR WEIGHT OF THE MIXTURE
      MW=(O2*32.+N2*28.+CO*28.+H2*2.+H2O*18.+CO2*44.)/MOLES
C  ALLOWING THE MEAN SPECIFIC HEAT TO BE DETERMINED
      DO 5 I=1,6
      SPHT=SPHT+CP(I)/MOLES/MW
    5 CONTINUE
      RETURN
      END
      FUNCTION DCPDT(T,O2,N2,CO,H2,H2O,CO2)
C  PROGRAM TO CALCULATE THE DERIVATIVE, WITH RESPECT TO T, OF THE MEAN
C  SPECIFIC HEAT BETWEEN T AND 60 DEGF OF A MIXTURE OF GASES....THE
C  GASES CONSIDERED ARE OXYGEN,NITROGEN, CARBON MONOXIDE, HYDROGEN,
C  WATER VAPOR, AND CARBON DIOXIDE
      REAL MW,MOLES,N2
      DIMENSION CP(6)
      DATA TDATUM/520./
      DCPDT=0.
      DELTA=T-TDATUM
C  FIRST CALCULATE THE DERIVATIVE OF THE INDIVIDUAL COMPONENTS OF THE
C  GAS USING THE RELATIONSHIPS OF SWEIGERT AND BEARDSLEY, REF. GEORGIA
C  INST. OF TECH. BULLETIN 2 (1938)
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      CP(1)=((11.515-172./SQRT(T)+1530./T)/DELTA-(11.515*DELTA-344.
     1*(SQRT(T)-SQRT(TDATUM))+1530.*(ALOG(T)-ALOG(TDATUM)))/DELTA**2)*O2
      CP(2)=((9.47-3.47E3/T+1.16E6/T**2)/DELTA-(9.47*DELTA-3.47E3*(
     1ALOG(T)-ALOG(TDATUM))-1.16E6*(1./T-1./TDATUM))/DELTA**2)*N2
      CP(3)=((9.46-3.29E3/T+1.07E6/T**2)/DELTA-(9.46*DELTA-3.29E3*
     1(ALOG(T)-ALOG(TDATUM))-1.07E6*(1./T-1./TDATUM))/DELTA**2)*CO
      CP(4)=((5.76+5.78E-4*T+20./SQRT(T))/DELTA-(5.76*DELTA+2.89E-4*
     1(T**2-TDATUM**2)+40.*(SQRT(T)-SQRT(TDATUM)))/DELTA**2)*H2
      CP(5)=((19.86-597./SQRT(T)+7500./T)/DELTA-(19.86*DELTA-1194.*
     1(SQRT(T)-SQRT(TDATUM))+7500.*(ALOG(T)-ALOG(TDATUM)))/DELTA**2)*H2O
      CP(6)=((16.2-6.53E3/T+1.41E6/T**2)/DELTA-(16.2*DELTA-6.53E3*
     1(ALOG(T)-ALOG(TDATUM))-1.41E6*(1./T-1./TDATUM))/DELTA**2)*CO2
C   THE TOTAL NUMBER OF MOLES IN THE MIXTURE
      MOLES=O2+N2+CO+H2+H2O+CO2
C   THE MOLECULAR WEIGHT OF THE MIXTURE
      MW=(O2*32.+N2*28.+CO*28.+H2*2.+H2O*18.+CO2*44.)/MOLES
C   ALLOWING THE DERIVATIVE OF THE SPECIFIC HEAT TO BE DETERMINED
      DO 5 I=1,6
      DCPDT=DCPDT+CP(I)/MOLES/MW
    5 CONTINUE
      RETURN
      END
      SUBROUTINE EQUATE
C   PROGRAM TO DETERMINE THE COMPOSITION OF THE PRODUCTS OF COMBUSTION
C   OF THE HYDROGEN AND CARBON IN THE WASTE....A DIFFUSION (LINEAR)
C   FLAME MECHANISM IS ASSUMED
      REAL N2,NIT
      COMMON/GASES/CO2,H2O(2),CO,O2(2),N2,H2
      COMMON/ELEMENT/HYD,NIT,OXY,CARBON(2),P(7)
C
C   ELEMENTAL OXYGEN AVAILABLE FOR COMBUSTION OF THE WASTE
      S=OXY+2.*O2(1)
C   OXYGEN REQUIRED FOR COMPLETE COMBUSTION
      STOICH=HYD/2.+2.*CARBON(1)
      IF (S.GE.STOICH) GO TO 15
C   STARVED AIR COMBUSTION OF THE HYDROGEN
      O2(2)=0.
      H2O(2)=S*HYD/2./STOICH
      H2=HYD/2.-H2O(2)
      S=S-H2O(2)
      IF (S.GE.CARBON(1)) GO TO 10
C   STARVED AIR COMBUSTION OF THE CARBON....NOT ENOUGH OXYGEN TO FORM
C   ANY CARBON DIOXIDE
      CO=S
      CARBON(2)=CARBON(1)-CO
      CO2=0.
      GO TO 20
   10 T=S-CARBON(1)
      CO2=T
      CO=CARBON(1)-T
      CARBON(2)=0.
      GO TO 20
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C  EXCESS AIR COMBUSTION
   15 H2O(2)=HYD/2.
      CO2=CARBON(1)
      H2=0.
      CARBON(2)=0.
      CO=0.
      O2(2)=S/2.-HYD/4.-CARBON(1)
   20 CONTINUE
C  CONVERT PRODUCTS OF COMBUSTION FROM MOLES TO LBS
      P(1)=CO2*44.
      P(2)=(H2O(1)+H2O(2))*18.
      P(3)=CO*28.
      P(4)=O2(2)*32.
      P(5)=N2*28.
      P(6)=H2*2.
      P(7)=CARBON(2)*12.
      RETURN
      END
      FUNCTION EMISS(T,L)
C  PROGRAM TO CALCULATE THE EMISSIVITY OF A MIXTURE OF COMBUSTION GASES.
C  CARBON DIOXIDE, WATER VAPOR, AND CARBON MONOXIDE ALL CONTRIBUTE AND
C  THEIR INDIVIDUAL EMISSIVITIES ARE OBTAINED FROM CURVE FITS OF THE
C  TABLES OF MCADAMS, "HEAT TRANSMISSION", MCGRAW-HILL,(1954)
      REAL L,MOLES,N2
      COMMON/GASES/CO2,H2O(2),CO,O2(2),N2,H2
      DATA DELTA/0./
C
C  CALCULATE THE PARTIAL PRESSURE OF INDIVIDUAL GASES IN ATMOSPHERES
C  ASSUMING A TOTAL PRESSURE OF ONE ATMOSPHERE
      MOLES=CO2+H2O(1)+H2O(2)+CO+O2(2)+N2+H2
      PCO2=CO2/MOLES
      PH2O=(H2O(1)+H2O(2))/MOLES
      PCO=CO/MOLES
C  THE INDEPENDENT VARIABLE IS PARTIAL PRESSURE TIMES MEAN BEAM LENGTH
      PCO2L=PCO2*L
      PH2OL=PH2O*L
      PCOL=PCO*L
C
C  CALCULATE EMISSIVITY OF CARBON DIOXIDE
      IF (PCO2L.LE.0.) GO TO 10
      POWER=-0.721+0.215*ALOG10(PCO2L)
      EMAX=-0.04+10.**POWER
      TMAX=2600.+800.*ALOG10(EMAX)
      POWER=((T-TMAX)/2800.)**2
      POWER=EXP(-POWER)-1.
      ECO2=EMAX*10.**POWER
C  CORRECT FOR OVERLAP WITH WATER VAPOR
      ECO2=ECO2-DELTA
      GO TO 15
   10 ECO2=0.
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C  CALCULATE EMISSIVITY OF WATER VAPOR
   15 IF (PH2OL.LE.0.) GO TO 20
      EMAX=2.+ALOG10(PH2OL)
      EMAX=-2.097+0.821*EMAX-0.1115*EMAX*(EMAX-1.)-0.00567*EMAX
     1*(EMAX-1.)*(EMAX-2.)
      POWER=(EMAX-0.59)*(T+5000.)/7000.+0.59
      EH2O=10.**POWER
C  CORRECT FOR PARTIAL PRESSURE OTHER THAN ZERO
      EH2O=EH2O*(1.+(0.62-0.1*ALOG(PH2OL))*PH2O)
      GO TO 25
   20 EH2O=0.
C  CALCULATE EMISSIVITY OF CARBON MONOXIDE
   25 IF (PCOL.LE.0.) GO TO 30
      POWER=-0.8477+0.1809*ALOG10(PCOL)
      EMAX=-0.0403+10.**POWER
      TMAX=1600.+3280.*(0.122-EMAX)
      POWER=((T-TMAX)/1800.)**2
      POWER=-1.+EXP(-POWER)
      ECO=EMAX*10.**POWER
C  CORRECT EMISSIVITY OF CO FOR OVERLAP WITH CO2
      ECO=0.7*ECO
      GO TO 35
   30 ECO=0.
C
C  CALCULATE THE TOTAL EMISSIVITY OF THE COMBUSTION GASES
   35 EMISS=ECO2+EH2O+ECO
      IF (EMISS.LE.1.) GO TO 50
      WRITE(6,1)
      WRITE(6,2)
      WRITE(6,3)
   50 RETURN
    1 FORMAT(1H0,////6X,"*************************************************
     1*****************************************************************")
    2 FORMAT(1H ,//6X,"EMISSIVITY GREATER THAN ONE.....THE GAS COMPOSITI
     1ON IS PROBABLY INCORRECT")
    3 FORMAT(1H ,//6X,"*************************************************
     1**************************************************************"//)
      END
      FUNCTION DEDT(T,L)
C  PROGRAM TO CALCULATE THE DERIVATIVE OF THE EMISSIVITY OF COMBUSTION
C  GASES WITH RESPECT TO TEMPERATURE.....CARBON DIOXIDE, WATER VAPOR,
C  AND CARBON MONOXIDE CONTRIBUTE TO TOTAL EMISSIVITY AND THEIR
C  INDIVIDUAL EMISSIVITIES ARE OBTAINED FROM CURVE FITS OF THE TABLES
C  OF MCADAMS, "HEAT TRANSMISSION", MCGRAW-HILL,(1954)
      REAL L,MOLES,N2
      COMMON/GASES/CO2,H2O(2),CO,O2(2),N2,H2
      DATA DDELDT/0./
C
C  CALCULATE THE PARTIAL PRESSURE OF INDIVIDUAL GASES IN ATMOSPHERES
C  ASSUMING A TOTAL PRESSURE OF ONE ATMOSPHERE
      MOLES=CO2+H2O(1)+H2O(2)+CO+O2(2)+N2+H2
      PCO2=CO2/MOLES
      PH2O=(H2O(1)+H2O(2))/MOLES
      PCO=CO/MOLES
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C  THE INDEPENDENT VARIABLE IS PARTIAL PRESSURE TIMES MEAN BEAM LENGTH
      PCO2L=PCO2*L
      PH2OL=PH2O*L
      PCOL=PCO*L
C
C  CALCULATE THE DERIVATIVE OF THE EMISS OF CO2 WITH RESPECT TO TEMP
      IF (PCO2L.LE.0.) GO TO 10
      POWER=-0.721+0.215*ALOG10(PCO2L)
      EMAX=-0.04+10.**POWER
      TMAX=2600.+800.*ALOG10(EMAX)
      POWER=((T-TMAX)/2800.)**2
      POWER1=EXP(-POWER)-1.
      DECO2=-5.87E-7*EMAX*10.**POWER1*EXP(-POWER)*(T-TMAX)
C  CORRECT FOR OVERLAP WITH WATER VAPOR
      DECO2=DECO2-DDELDT
      GO TO 15
   10 DECO2=0.
C  CALCULATE THE DERIVATIVE OF THE EMISS OF H2O WITH RESPECT TO TEMP
   15 IF (PH2OL.LE.0.) GO TO 20
      EMAX=2.+ALOG10(PH2OL)
      EMAX=-2.097+0.821*EMAX-0.1115*EMAX*(EMAX-1.)-0.00567*EMAX
     1*(EMAX-1.)*(EMAX-2.)
      POWER=(EMAX-0.59)*(T+5000.)/7000.+0.59
      DEH2O=3.29E-4*10.**POWER*(EMAX-0.59)
C  CORRECT FOR PARTIAL PRESSURE OTHER THAN ZERO
      DEH2O=DEH2O*(1.+(0.62-0.1*ALOG(PH2OL))*PH2O)
      GO TO 25
   20 DEH2O=0.
C  CALCULATE THE DERIVATIVE OF THE EMISS OF CO WITH RESPECT TO TEMP
   25 IF (PCOL.LE.0.) GO TO 30
      POWER=-0.8477+0.1809*ALOG10(PCOL)
      EMAX=-0.0403+10.**POWER
      TMAX=1600.+3280.*(0.122-EMAX)
      POWER=((T-TMAX)/1800.)**2
      POWER1=EXP(-POWER)-1.
      DECO=-1.42E-6*EMAX*10.**POWER1*EXP(-POWER)*(T-TMAX)
C  CORRECT EMISSIVITY OF CO FOR OVERLAP WITH CO2
      DECO=0.7*DECO
      GO TO 35
   30 DECO=0.
C
C  CALCULATE THE DERIVATIVE OF THE TOTAL EMISSIVITY OF THE COMBUSTION
C  GASES WITH RESPECT TO GAS TEMPERATURE
   35 DEDT=DECO2+DEH2O+DECO
      RETURN
      END
      SUBROUTINE MINV(A,N,D,L,M)
C
C     .................................................................
C
```

```
C        SUBROUTINE MINV
C
C        PURPOSE
C           INVERT A MATRIX
C
C        USAGE
C           CALL MINV(A,N,D,L,M)
C
C        DESCRIPTION OF PARAMETERS
C           A - INPUT MATRIX, DESTROYED IN COMPUTATION AND REPLACED BY
C               RESULTANT INVERSE.
C           N - ORDER OF MATRIX A
C           D - RESULTANT DETERMINANT
C           L - WORK VECTOR OF LENGTH N
C           M - WORK VECTOR OF LENGTH N
C
C        REMARKS
C           MATRIX A MUST BE A GENERAL MATRIX
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           THE STANDARD GAUSS-JORDAN METHOD IS USED. THE DETERMINANT
C           IS ALSO CALCULATED. A DETERMINANT OF ZERO INDICATES THAT
C           THE MATRIX IS SINGULAR.
C
C     ..................................................................
C
      DIMENSION A(1),L(1),M(1)
C
C        ...............................................................
C
C        IF A DOUBLE PRECISION VERSION OF THIS ROUTINE IS DESIRED, THE
C        C IN COLUMN 1 SHOULD BE REMOVED FROM THE DOUBLE PRECISION
C        STATEMENT WHICH FOLLOWS.
C
C     DOUBLE PRECISION A,D,BIGA,HOLD
C
C        THE C MUST ALSO BE REMOVED FROM DOUBLE PRECISION STATEMENTS
C        APPEARING IN OTHER ROUTINES USED IN CONJUNCTION WITH THIS
C        ROUTINE.
C
C        THE DOUBLE PRECISION VERSION OF THIS SUBROUTINE MUST ALSO
C        CONTAIN DOUBLE PRECISION FORTRAN FUNCTIONS.  ABS IN STATEMENT
C        10 MUST BE CHANGED TO DABS.
C
C        ...............................................................
C
```

```
C        SEARCH FOR LARGEST ELEMENT
C
      D=1.0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
   10 IF( ABS(BIGA)- ABS(A(IJ))) 15,20,20
   15 BIGA=A(IJ)
      L(K)=I
      M(K)=J
   20 CONTINUE
C
C        INTERCHANGE ROWS
C
      J=L(K)
      IF(J-K) 35,35,25
   25 KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   30 A(JI) =HOLD
C
C        INTERCHANGE COLUMNS
C
   35 I=M(K)
      IF(I-K) 45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI) =HOLD
C
C        DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
C        CONTAINED IN BIGA)
C
```

```
   45 IF(BIGA) 48,46,48
   46 D=0.0
      RETURN
   48 DO 55 I=1,N
      IF(I-K) 50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
C
C        REDUCE MATRIX
C
      DO 65 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K) 60,65,60
   60 IF(J-K) 62,65,62
   62 KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
   65 CONTINUE
C
C        DIVIDE ROW BY PIVOT
C
      KJ=K-N
      DO 75 J=1,N
      KJ=KJ+N
      IF(J-K) 70,75,70
   70 A(KJ)=A(KJ)/BIGA
   75 CONTINUE
C
C        PRODUCT OF PIVOTS
C
      D=D*BIGA
C
C        REPLACE PIVOT BY RECIPROCAL
C
      A(KK)=1.0/BIGA
   80 CONTINUE
C
C        FINAL ROW AND COLUMN INTERCHANGE
C
      K=N
  100 K=(K-1)
      IF(K) 150,150,105
  105 I=L(K)
      IF(I-K) 120,120,108
```

```
108 JQ=N*(K-1)
    JR=N*(I-1)
    DO 110 J=1,N
    JK=JQ+J
    HOLD=A(JK)
    JI=JR+J
    A(JK)=-A(JI)
110 A(JI) =HOLD
120 J=M(K)
    IF(J-K) 100,100,125
125 KI=K-N
    DO 130 I=1,N
    KI=KI+N
    HOLD=A(KI)
    JI=KI-K+J
    A(KI)=-A(JI)
130 A(JI) =HOLD
    GO TO 100
150 RETURN
    END
```

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Table 1. Comparing HRI Predictions With the Measured Performance of the Incinerator at the Naval Station, Mayport, Fla.

Variable	Measured Value[a] 9 Dec 1980	HRI Prediction
PCC gas temperature, °F	1,193	1,163
PCC outside wall temperature, °F	175	197
SCC gas temperature, °F	1,578	1,499
SCC outside wall temperature, °F	221	224
Stack gas temperature, °F	470	509
Steam generation, lb/hr	7,958	8,657
Overall efficiency	0.49	0.48

[a]Reference 9.

Table 2. Program "HRI" Input Format

10	20	30	40	50	60	70	80
FUEL	HHV(1)						
C(1)	H(1)	O(1)	N(1)	X(1)			
WATER	VM	FC	ASHE				
ASH	HHV(2)						
C(2)	H(2)	O(2)	N(2)	X(2)			
OIL(1)	OIL(2)	HHV(3)					
C(3)	H(3)	O(3)	N(3)	X(3)			
KW							
AIRPCC	AIROF	AIRSCC	AIROIL(1)	AIROIL(2)			
LEAK(1)	LEAK(2)	LEAK(3)					
AFLAME	APCC	ASCC	HCONV(1)	HCONV(2)	HCONV(3)	KWALL(1)	KWALL(2)
TAMB	ESHELL	LPCC	LSCC				
TYPE							
ABOIL	TFEED(1)	HFEED(1)	TSTM(1)	HSTM(1)	HEVAP	PSTM(1)	BD(1)
U	TIN	TOUT	FLOW				
TSTM(2)	PSTM(2)	HSTM(2)	TFEED(2)	HFEED(2)	BD(2)		
TSTM(3)	PSTM(3)	HSTM(3)	TFEED(3)	HFEED(3)	BD(3)		

Table 3. Program HRI Input Variables

Variable	Definition	Units	Comments
FUEL	Feed rate of the wet fuel (waste)	lb/hr	
HHV(1)	Higher heating value of the fuel	Btu/lb	
C(1)	Carbon content of fuel as determined by ultimate analysis	% of dry weight	
H(1)	Hydrogen content of fuel		
O(1)	Oxygen content of fuel		
N(1)	Nitrogen content of fuel		
X(1)	Amount of everything else (other than carbon, hydrogen, oxygen, nitrogen) contained in the fuel as determined by ultimate analysis		
WATER	Moisture in fuel as determined by proximate analysis	% of dry weight	
VM	Volatile matter in the fuel		
FC	Fixed carbon in the fuel		
ASHE	Ash content of fuel		
ASH	Removal rate of ash	lb/hr	
HHV(2)	Higher heating value of ash	Btu/hr	
C(2)	Carbon content of ash as determined by ultimate analysis	% of dry weight	
H(2)	Hydrogen content of ash		
O(2)	Oxygen content of ash		
N(2)	Nitrogen content of ash		
X(2)	Amount of everything other than carbon, hydrogen, oxygen, and nitrogen contained in ash		
OIL(1)	Oil supplied to PCC burner	lb/hr	

continued

Table 3. Continued

Variable	Definition	Units	Comments
OIL(2)	Oil supplied to SCC burner	lb/hr	
HHV(3)	Higher heating value of the oil	Btu/lb	
C(3)	Carbon content of the oil as determined by ultimate analysis	% of dry weight	
H(3)	Hydrogen content of oil		
O(3)	Oxygen content of oil		
N(3)	Nitrogen content of oil		
X(3)	Amount of everything other than carbon, hydrogen, oxygen, and nitrogen contained in the oil		
KW	Sum of all external power requirements	kW	
AIRPCC	Underfire air	lb/min	
AIROF	Overfire air	lb/min	
AIRSCC	Combustion air supplied to SCC	lb/min	
AIROIL(1)	Combustion air supplied to primary oil burner	lb/min	
AIROIL(2)	Combustion air supplied to secondary oil burner	lb/min	
LEAK(1)	Air leakage into or out of the PCC	lb/min	Negative leakage is out of the incinerator
LEAK(2)	Air leakage into or out of the SCC	lb/min	
LEAK(3)	Air leakage down the dump stack	lb/min	
AFLAME	Surface area of the hearth covered by the flame	ft^2	
APCC	Surface area of PCC walls	ft^2	
ASCC	Surface area of SCC walls	ft^2	

continued

Table 3. Continued

Variable	Definition	Units	Comments
HCONV(1)	Convective heat transfer coefficient of inner walls of PCC	Btu/hr-ft^2-°F	
HCONV(2)	Convective heat transfer coefficient of inner walls of SCC	Btu/hr-ft^2-°F	
HCONV(3)	Convective heat transfer coefficient of all outer walls of incinerator	Btu/hr-ft^2-°F	
KWALL(1)	Thermal conductance of PCC walls	Btu/hr-ft^2-°F	Thermal conductivity divided by thickness
KWALL(2)	Thermal conductance of SCC walls	Btu/hr-ft^2-°F	
TAMB	Ambient air temperature	°F	
ESHELL	Emissivity of the outer shell of the incinerator	Dimensionless	
LPCC	Mean beam length of the PCC	ft	
LSCC	Mean beam length of the SCC	ft	
TYPE	Code to designate the incinerator configuration: "1" signifies no boilers "2" signifies convection boiler at SCC exit "3" signifies PCC waterwalls "4" signifies SCC waterwalls "5" signifies both PCC waterwalls and convection boiler at SCC exit "6" signifies both SCC waterwalls and convection boiler at SCC exit "7" signifies both PCC and SCC waterwalls		This is the only integer input and the only variable input in a field width of five

continued

Table 3. Continued

Variable	Definition	Units	Comments
TYPE	"8" signifies PCC waterwalls, SCC waterwalls, and convection boiler at SCC exit		
ABOIL	Total surface area of the tubes of the convection boiler	ft^2	If there is no convection boiler, the applicable inputs are omitted
TFEED(1)	Temperature of the feed water to the convection boiler	°F	
HFEED(1)	Enthalpy of the feed water to the convection boiler	Btu/lb	
TSTM(1)	Temperature of the steam leaving the convection boiler	°F	
HSTM(1)	Enthalpy of the steam leaving the convection boiler	Btu/lb	
HEVAP	Enthalpy of the feed water at saturation	Btu/lb	
PSTM(1)	Pressure of the steam leaving the convection boiler	psia	
BD(1)	Blowdown loss from the convection boiler	Fraction of steam generated	
U	Convection boiler overall heat transfer coefficient under design conditions	Btu/hr-ft^2-°F	"U" is the overall heat transfer coefficient of a boiler designed to handle FLOW lb/hr of combustion gases entering at TIN °F and exiting at TOUT °F
TIN	Temperature of combustion gases entering convection boiler under design conditions	°F	
TOUT	Temperature of combustion gases exiting convection boiler under design conditions	°F	

continued

Table 3. Continued

Variable	Definition	Units	Comments
FLOW	Flow rate of combustion gases passing through convection boiler operating under design conditions	lb/hr	
TSTM(2)	Temperature of steam leaving PCC waterwalls waterwalls	°F	If there are no primary combustion chamber water-walls, the appli-cable inputs are omitted
PSTM(2)	Pressure of steam leaving PCC waterwalls	psia	
HSTM(2)	Enthalpy of steam leaving PCC waterwalls	Btu/lb	
TFEED(2)	Temperature of feed water to PCC waterwalls	°F	
HFEED(2)	Enthalpy of feed water to PCC waterwalls	Btu/lb	
BD(2)	Blowdown loss from PCC waterwalls	Fraction of steam generated	
TSTM(3)	Temperature of steam leaving SCC waterwalls	°F	
PSTM(3)	Pressure of steam leaving SCC waterwalls	psia	
HSTM(3)	Enthalpy of steam leaving SCC waterwalls	Btu/lb	
TFEED(3)	Temperature of feed water to SCC waterwalls	°F	
HFEED(3)	Enthalpy of feed water to SCC waterwalls	Btu/lb	
BD(3)	Blowdown loss from SCC waterwalls	Fraction of steam generated	

Table 4. Suggested Convection Heat Transfer Coefficients

Variable Name	Magnitude (Btu/hr-ft^2-°F)
HCONV (1) and HCONV (2)	5 to 50
HCONV (3)	1 to 5

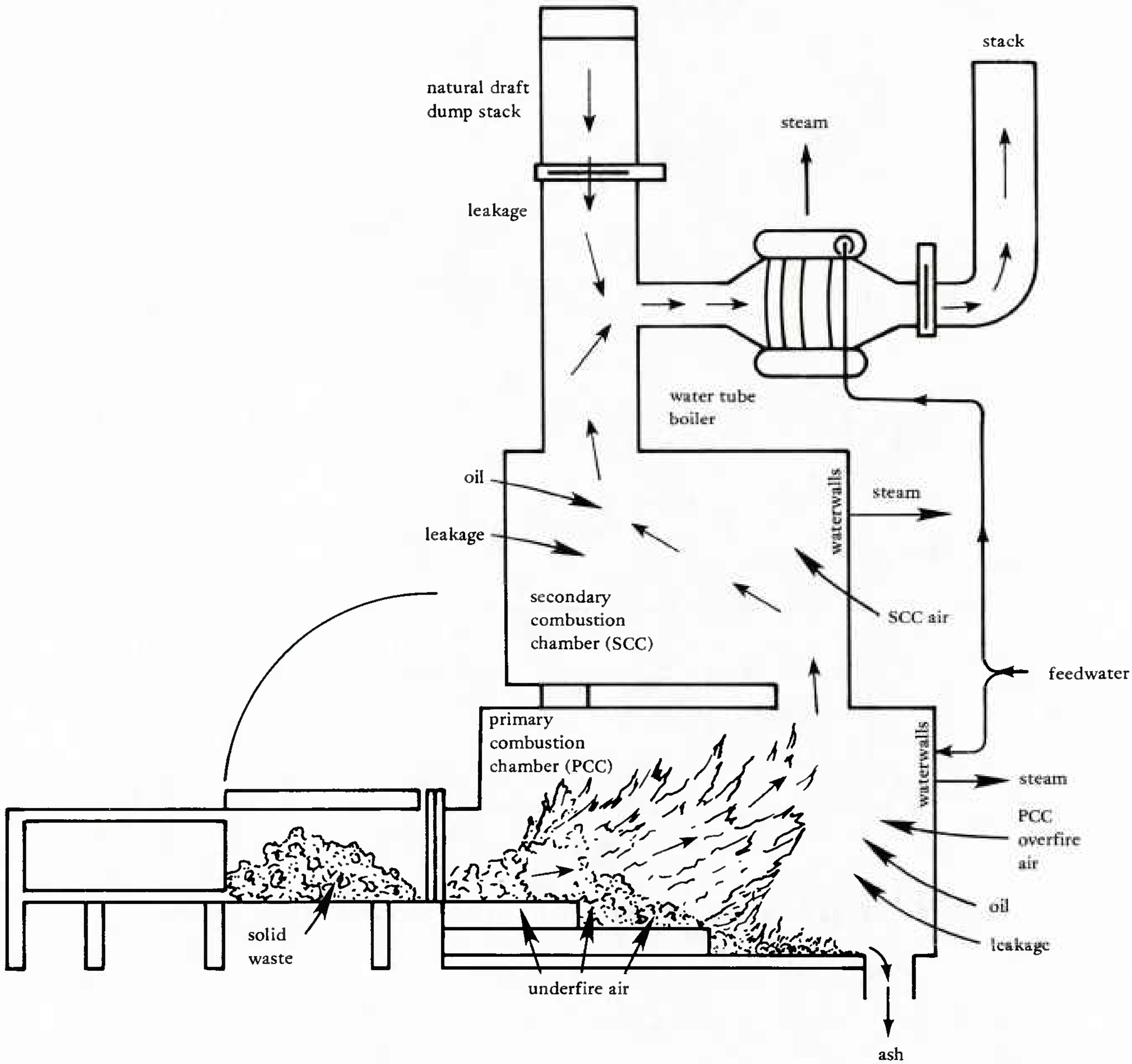

Figure 1. HRI configuration options.

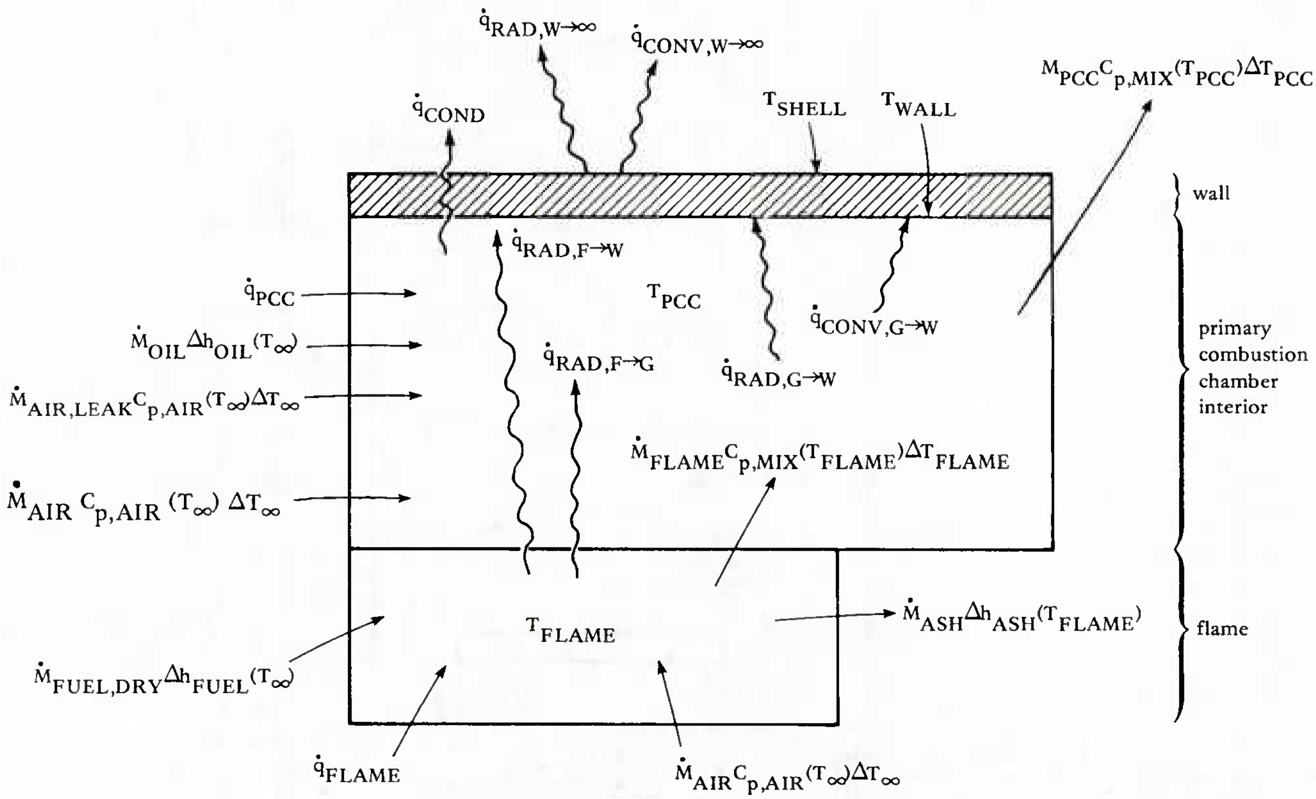

Figure 2. Conservation of energy in primary combustion chamber.

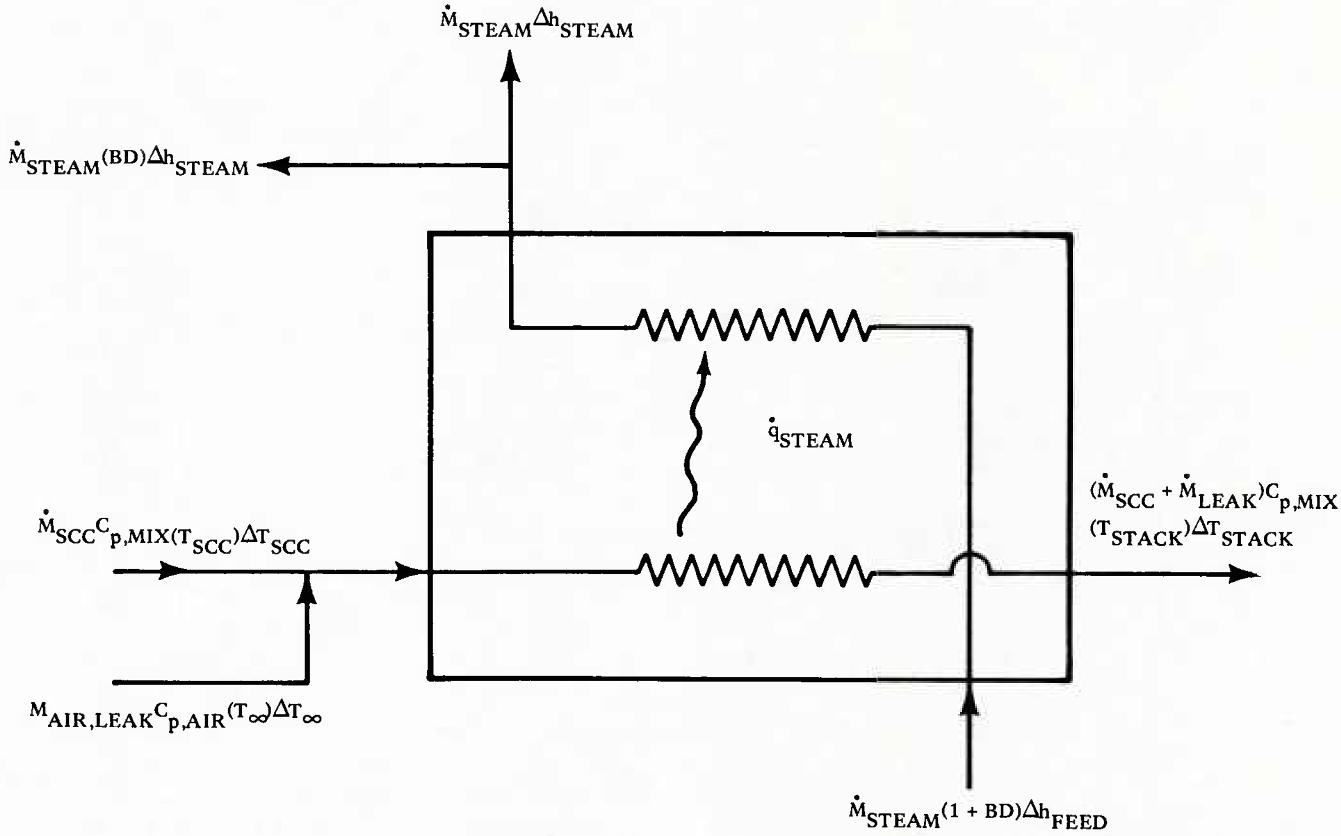

Figure 3. Conservation of energy in energy recovery boiler.

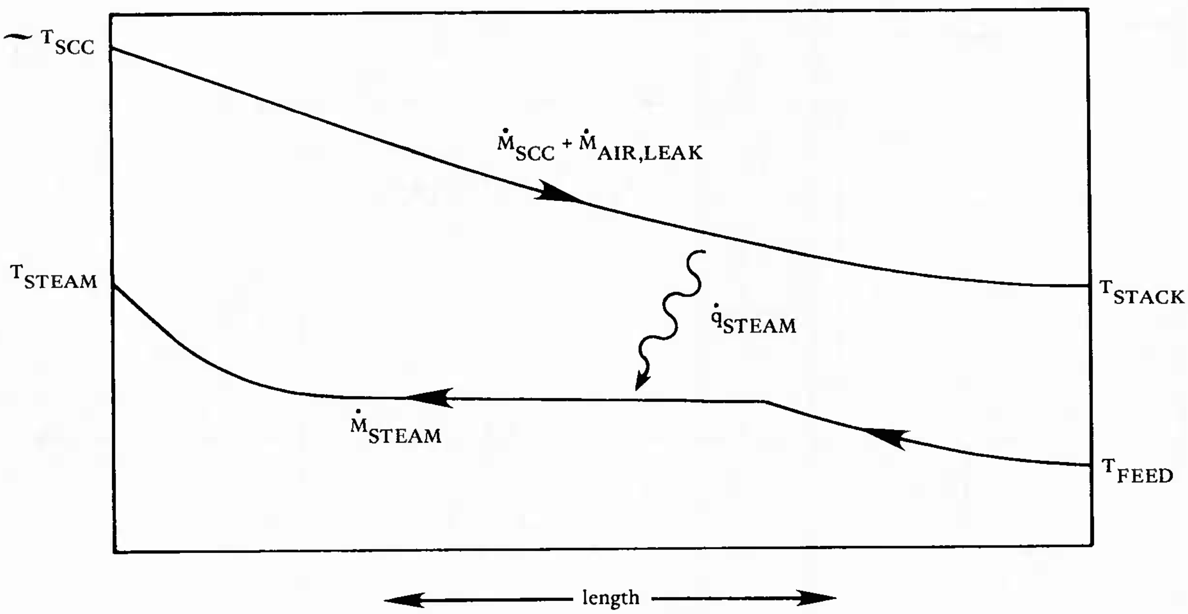

Figure 4. Typical temperature variations through heat recovery boiler.

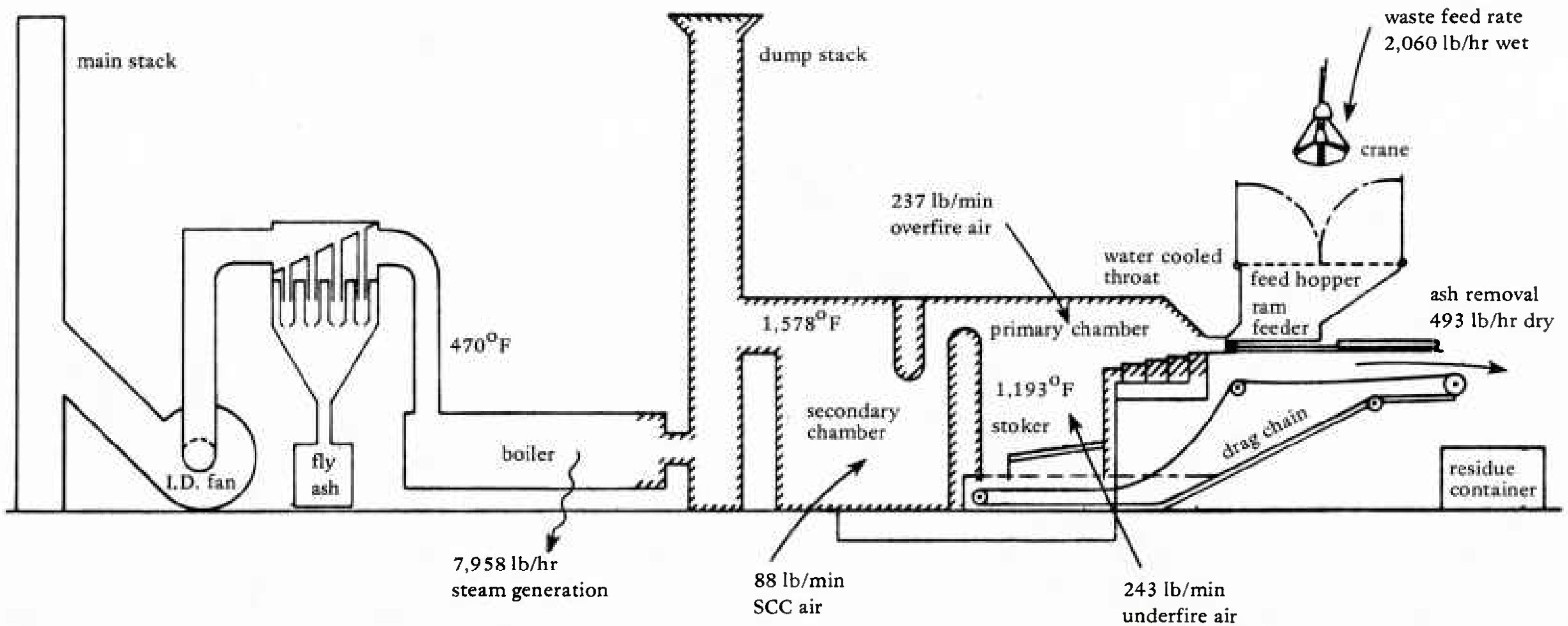

Figure 5. Cross section of incineration heat recovery system at the Naval Station, Mayport, Fla. (from Ref 9).

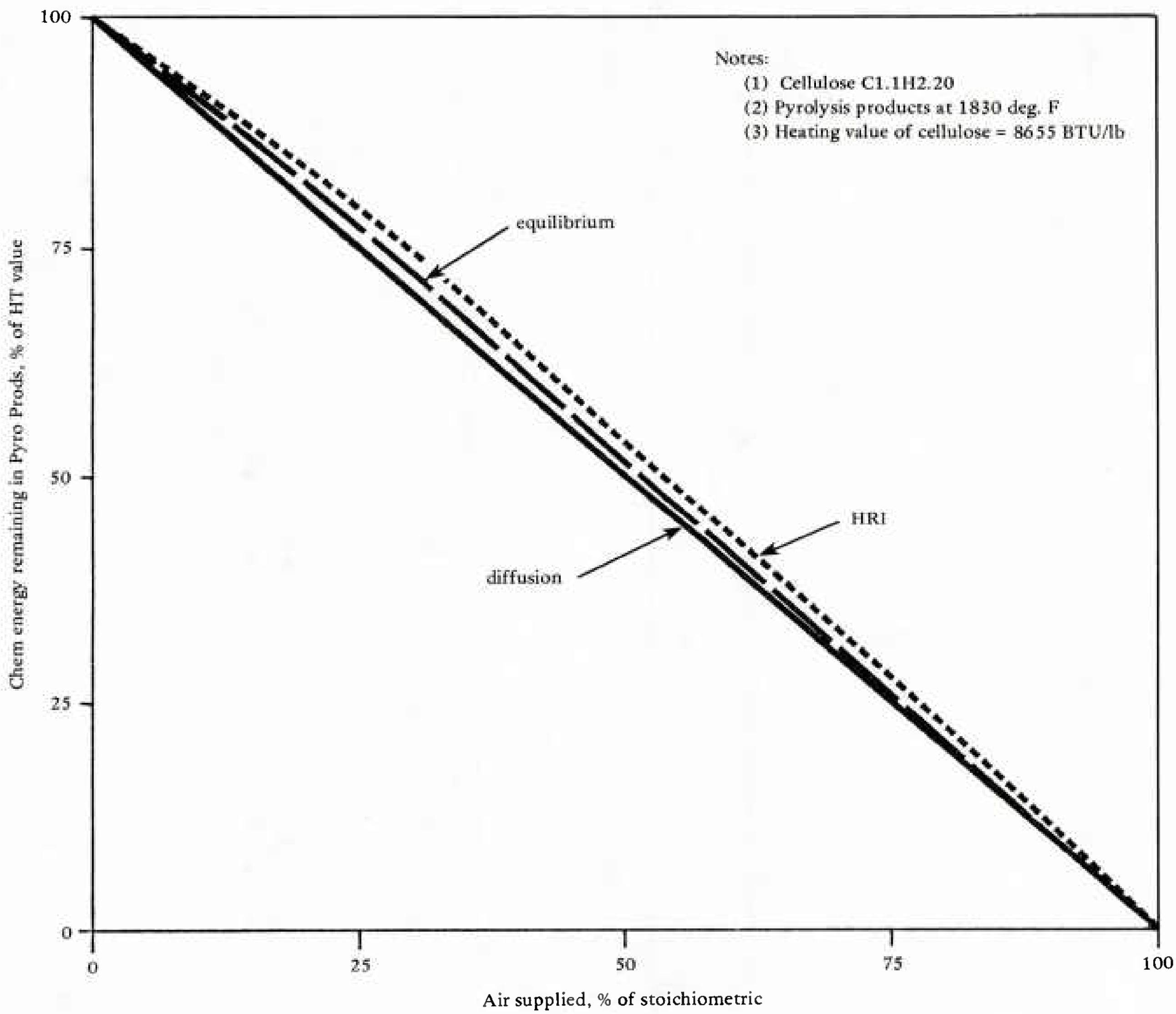

Figure 6. Comparison of equilibrium and diffusion models in predicting the progress of starved air combustion of cellulose.

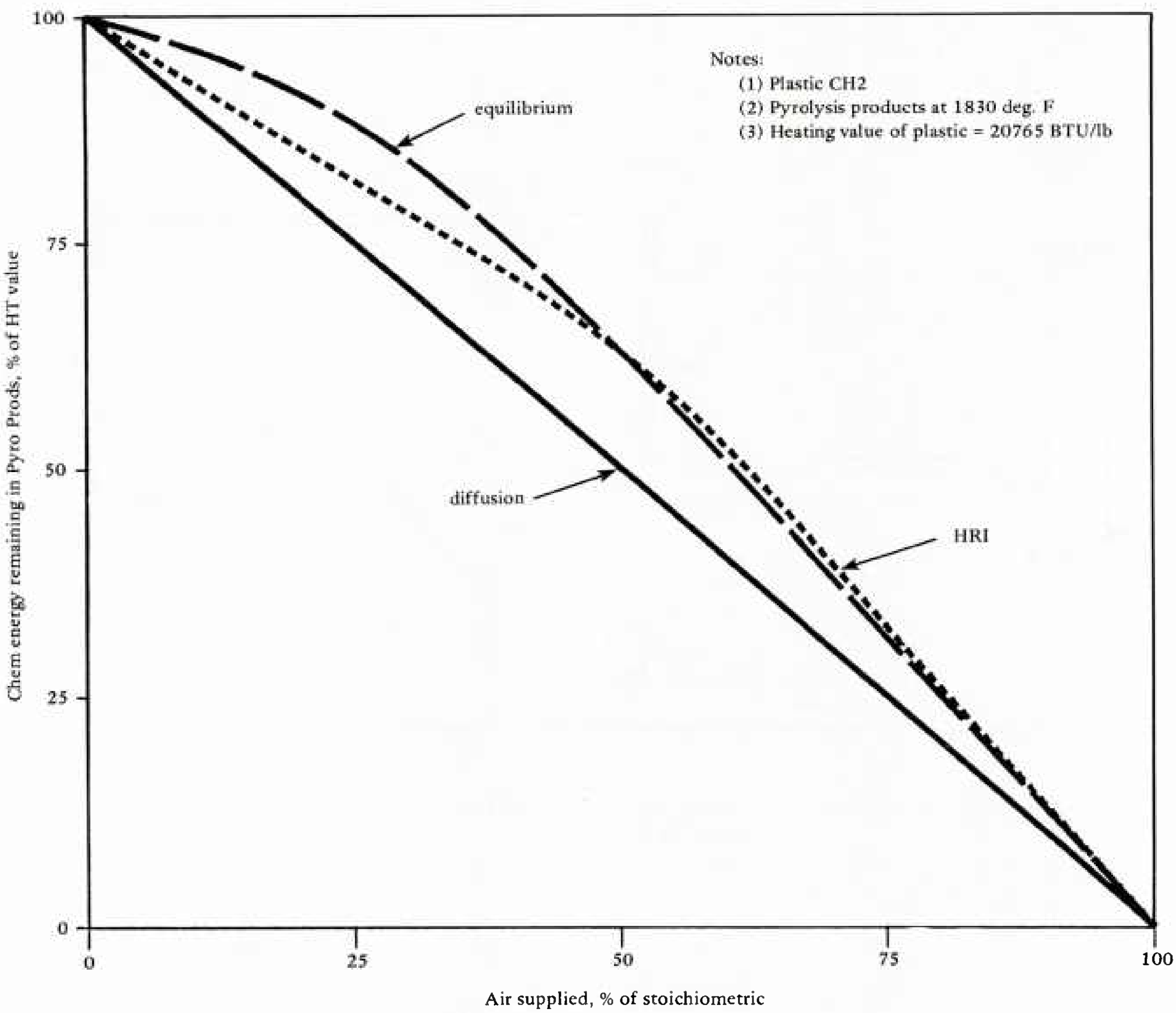

Figure 7. Comparison of equilibrium and diffusion models in predicting the progress of starved air combustion of plastic.

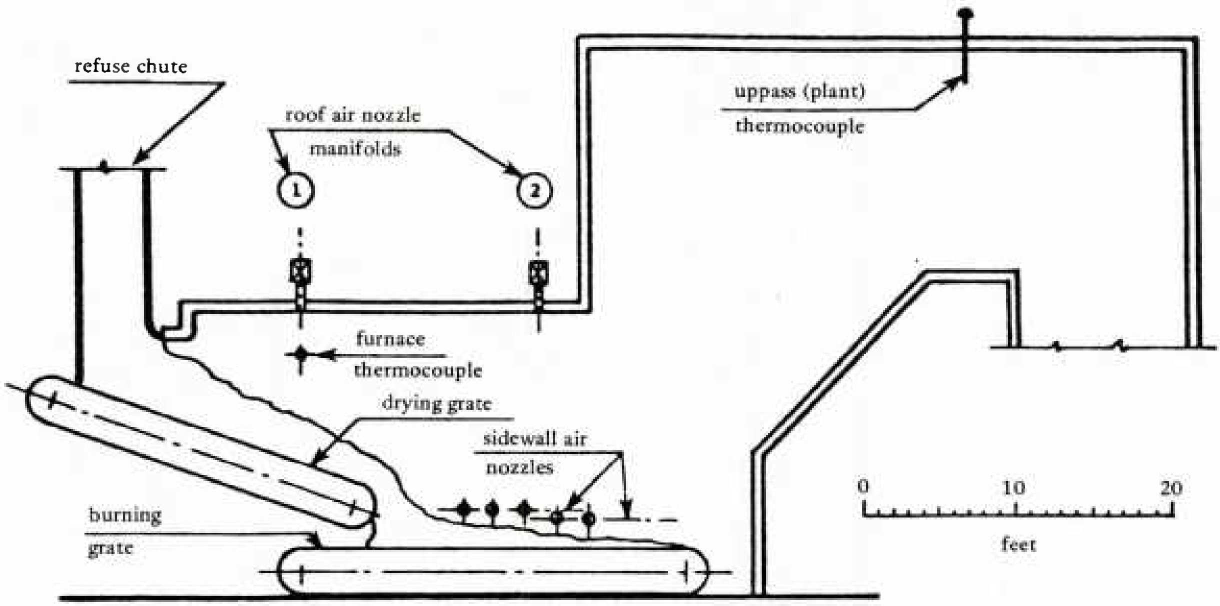

Figure 8. Schematic of Morse Boulger plant no. 1 (from Ref 15).

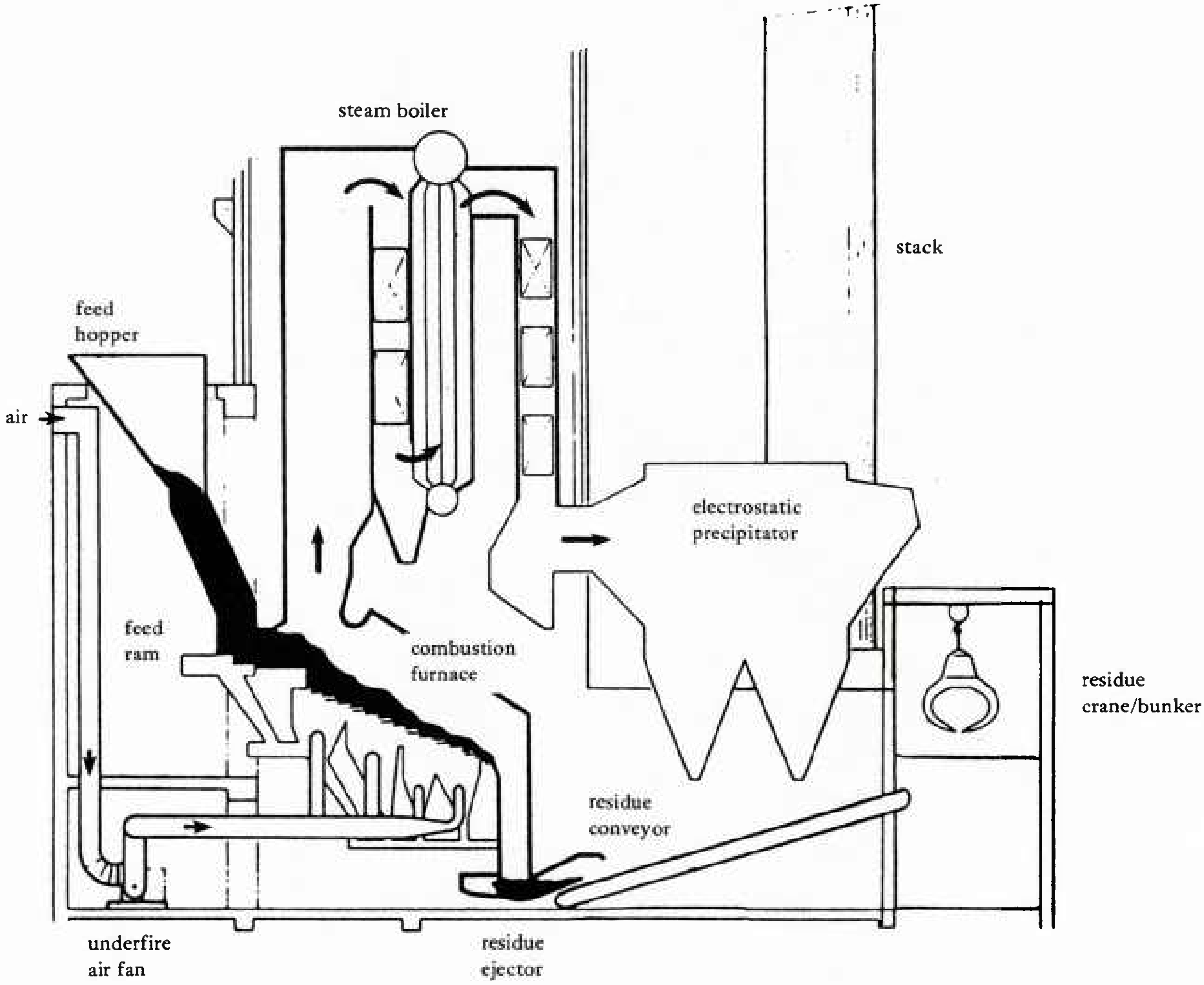

Figure 9. Schematic drawing of unit no. 3 equipment cross section for Besancon, France, HRI facility (from Ref 17).

Appendix

HRI ON A PERSONAL COMPUTER

by
K. D. Miller

This appendix explains how to operate the program HRI on an IBM PC or a Zenith 120. Characteristics of running the program on a personal computer (PC), inputting data, and printing the output will be covered.

The program HRI was downloaded from a mainframe computer to the IBM PC. The compiler used on the PC was MICROSOFT's FORTRAN 77 compiler, version 3.20. Since HRI is about 1,400 lines long, it is necessary to compile the program on a hard disk instead of a floppy disk. It is important to make and use a back-up copy of this disk because of the compiling difficulty. The floppy disk contains the following programs:

- HRI.FOR - The source code (program listing) for the main program HRI.
- HRI.EXE - The compiled version of HRI.
- HRI.DAT - A file containing a sample set of data to run with the program HRI.
- HRT.FOR - The source code (program listing) for the program HRT, which enters data into HRI.DAT.
- HRT.EXE - The compiled version of HRT.

The PC version of the program HRI has been slightly modified. The program reads input from the file HRI.DAT, and it sends the output to a file called HRI.OUT instead of to the screen. To make inputting the data easier, an optional program called HRT.FOR has been created. This program asks the user to enter the data item by item, and it places the data in the file HRI.DAT.

Before running the program HRI, load the IBM-DOS disk, or the Z-DOS disk if using a Zenith 120, in drive A and the disk containing the HRI and HRT programs in drive B. The system should be set with drive B as the default drive.

The program is begun by typing HRT. Information is then displayed on the screen, and the first prompt asks for the mass flow rate of the fuel in lb/hr. If a single variable is asked for, simply type in the number and hit RETURN. When multiple variables are asked for, the data must be separated by spaces, commas, or RETURNS. It is not possible to skip a prompt; data or zeros must be entered for each prompt.

Once the program HRT has been completed, it is possible to correct any mistakes made while entering the data. This is also an advantage if only one or two parameters need to be changed for additional runs of HRI. The file HRI.DAT can be edited by using whatever type of editor is available. Some examples of editors are EDLIN and WordStar.

When the data are correct, the main program is run by typing HRI. No inputs are asked for from the screen. Note that the program HRI will run without having first run HRT, using whatever data are currently in HRI.DAT. The message "Stop -- Program Terminated" is displayed when execution has been completed. The output is contained in the file HRI.OUT. To obtain a hard copy of the output, type TYPE HRI.OUT with the printer activated. The output is in the same format as the mainframe version. The data contained in the file HRI.DAT are kept until the program HRT is run again. So if only one or two variables are to be changed, it is faster to directly edit the file HRI.DAT instead of rerunning HRT. The data in the file HRI.OUT are kept until the program HRI is run again. Therefore, if the output files are to be permanently kept, they should be copied onto another disk.

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